UNIVERSIDAD DE CANTABRIA

Departamento de Ingeniería de Comunicaciones

TESIS DOCTORAL

Cryogenic Technology in the Microwave Engineering: Application to MIC and MMIC Very Low Noise Amplifier Design

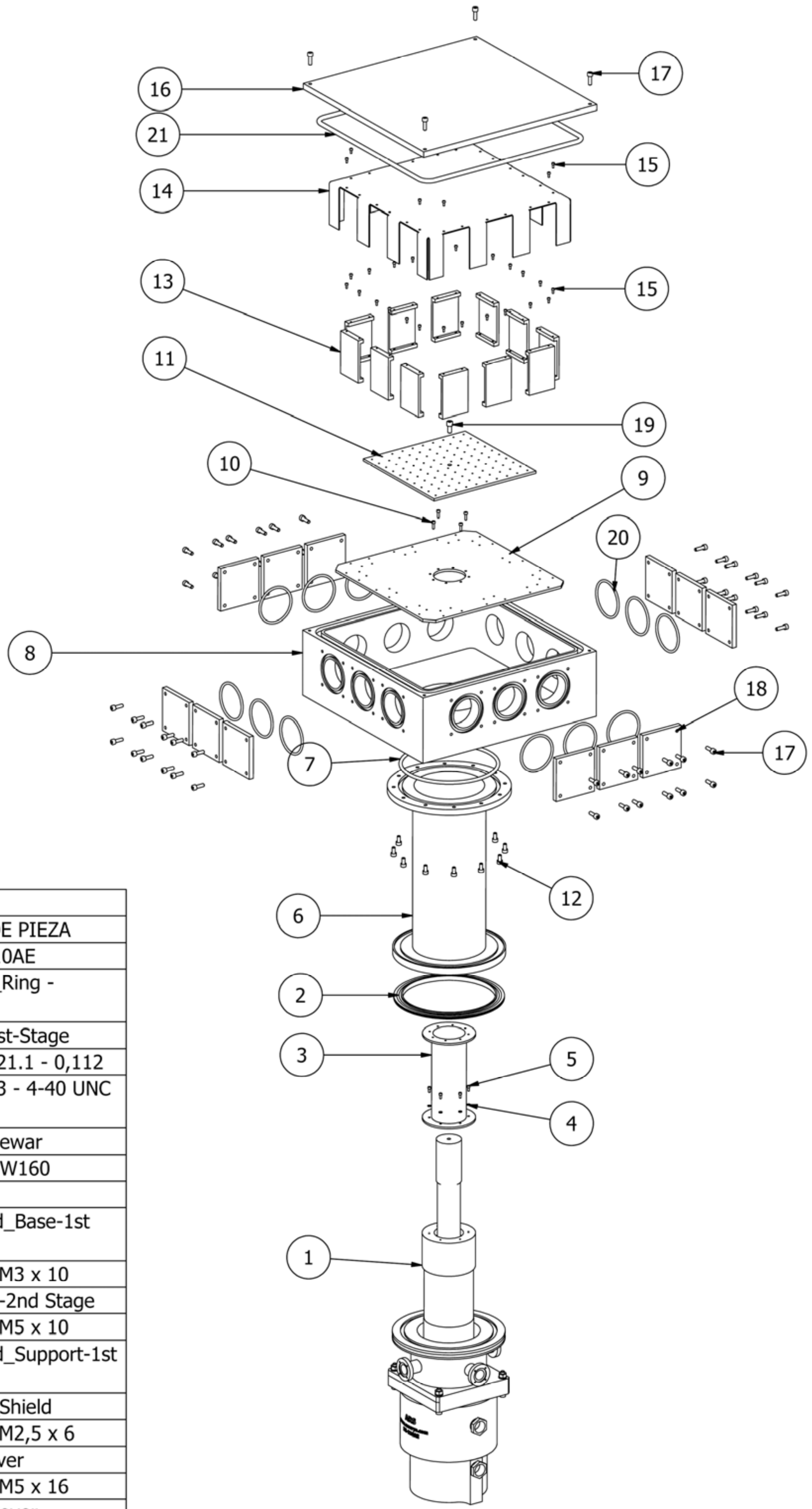
Juan Luis Cano de Diego

Santander, Mayo 2010

Annex I

Cryostat Drawings

No.	Drawing Name	Description
1	Despiece ARS210AE	Exploded view of the cryogenic system ARS210AE
2	Dewar	Cryostat box (Dewar)
3	Support_Dewar	Cryostat to Dewar transition
4	Support_1st-Stage	Cryostat 1st stage to radiation shield transition
5	Dewar_Cover	Cryostat box lid
6	Radiation_Shield	Radiation shield cover
7	Window_Cover	Dewar window lid
8	Rad_Shield_Support	Radiation shield support walls
9	Rad_Shield_Base	Radiation shield base
10	Cold_Plate	Second stage base
11	Contorno	Outer main dimensions when assembled



Lista de piezas		
ELEMENTO	CTDAD	Nº DE PIEZA
1	1	ARS DE-210AE
2	1	Centering_Ring - NW160
3	1	Support_1st-Stage
4	6	ANSI B18.21.1 - 0,112
5	6	ANSI B18.3 - 4-40 UNC - 0,25
6	1	Support_Dewar
7	1	O-Ring - NW160
8	1	Dewar
9	1	Rad_Shield_Base-1st Stage
10	4	BS 4168 - M3 x 10
11	1	Cold_Plate-2nd Stage
12	12	BS 4168 - M5 x 10
13	12	Rad_Shield_Support-1st Stage
14	1	Radiation_Shield
15	32	BS 4168 - M2,5 x 6
16	1	Dewar_Cover
17	52	BS 4168 - M5 x 16
18	12	Window_Cover
19	1	ANSI B18.3 - 1/4-28 UNF - 0,5
20	12	O-Ring - 57mm
21	1	O-Ring - 380mm

Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				24/03/2008

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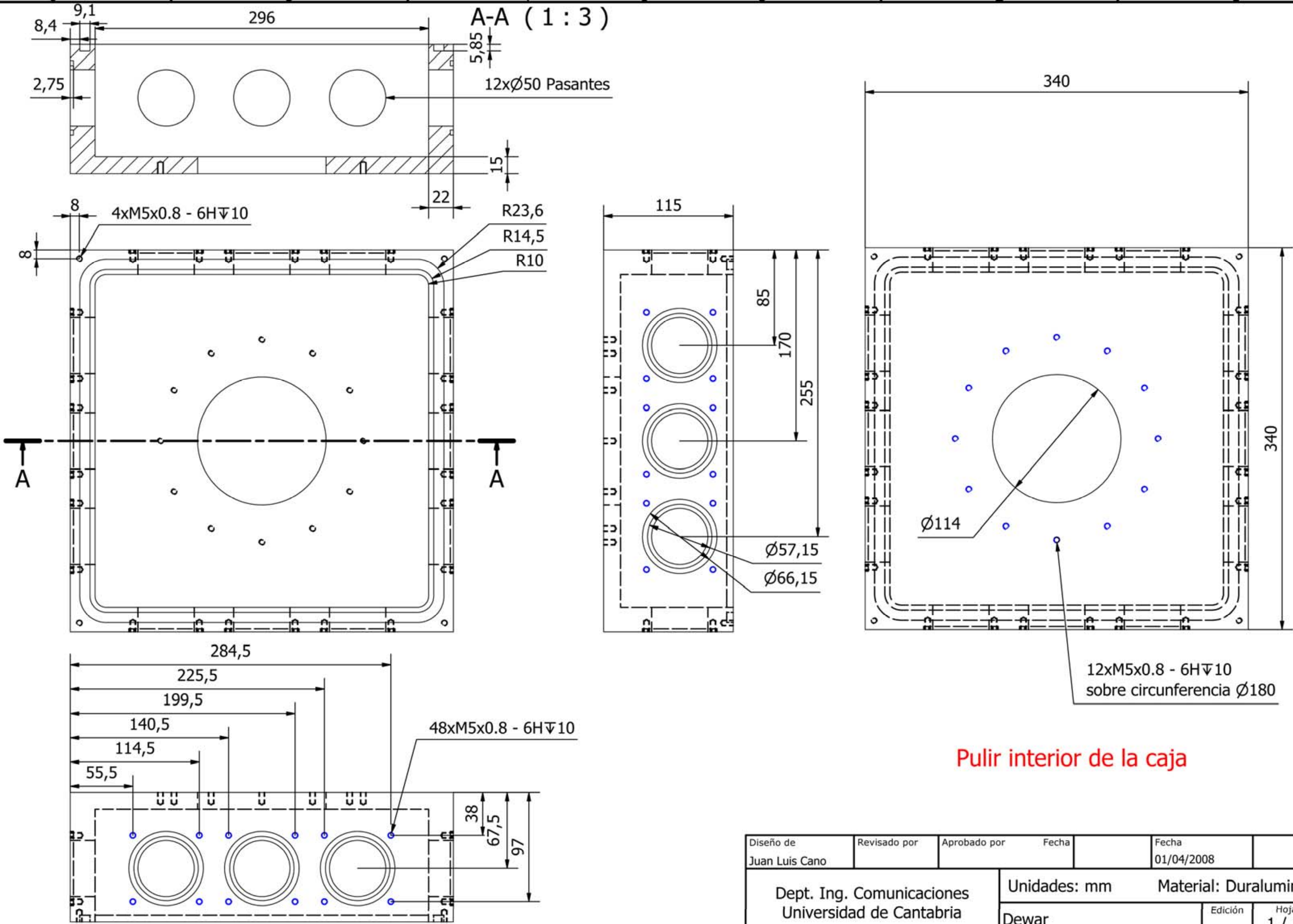
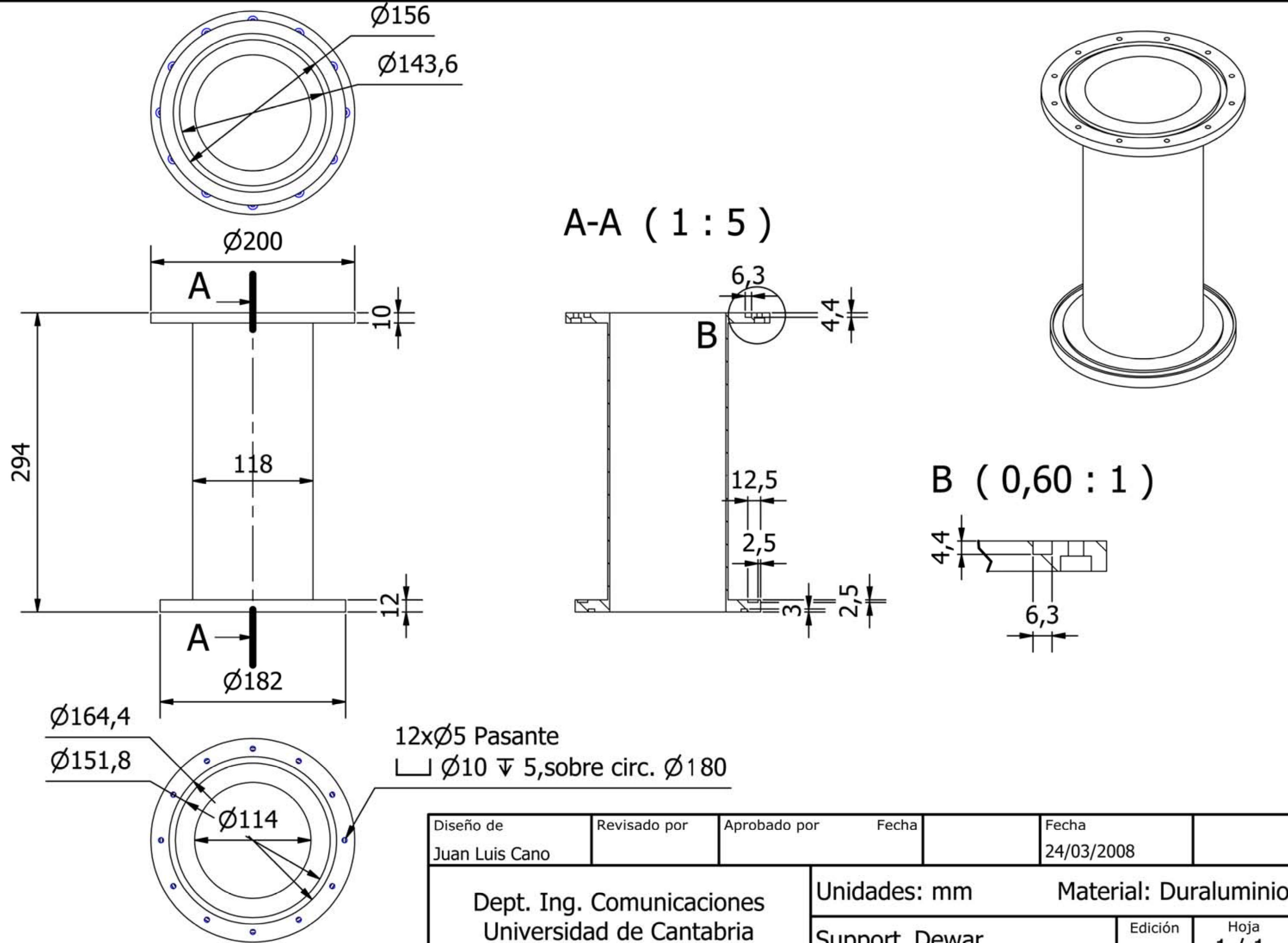
Conjunto ARS DE-210AE - Caja

Despiece ARS210AE

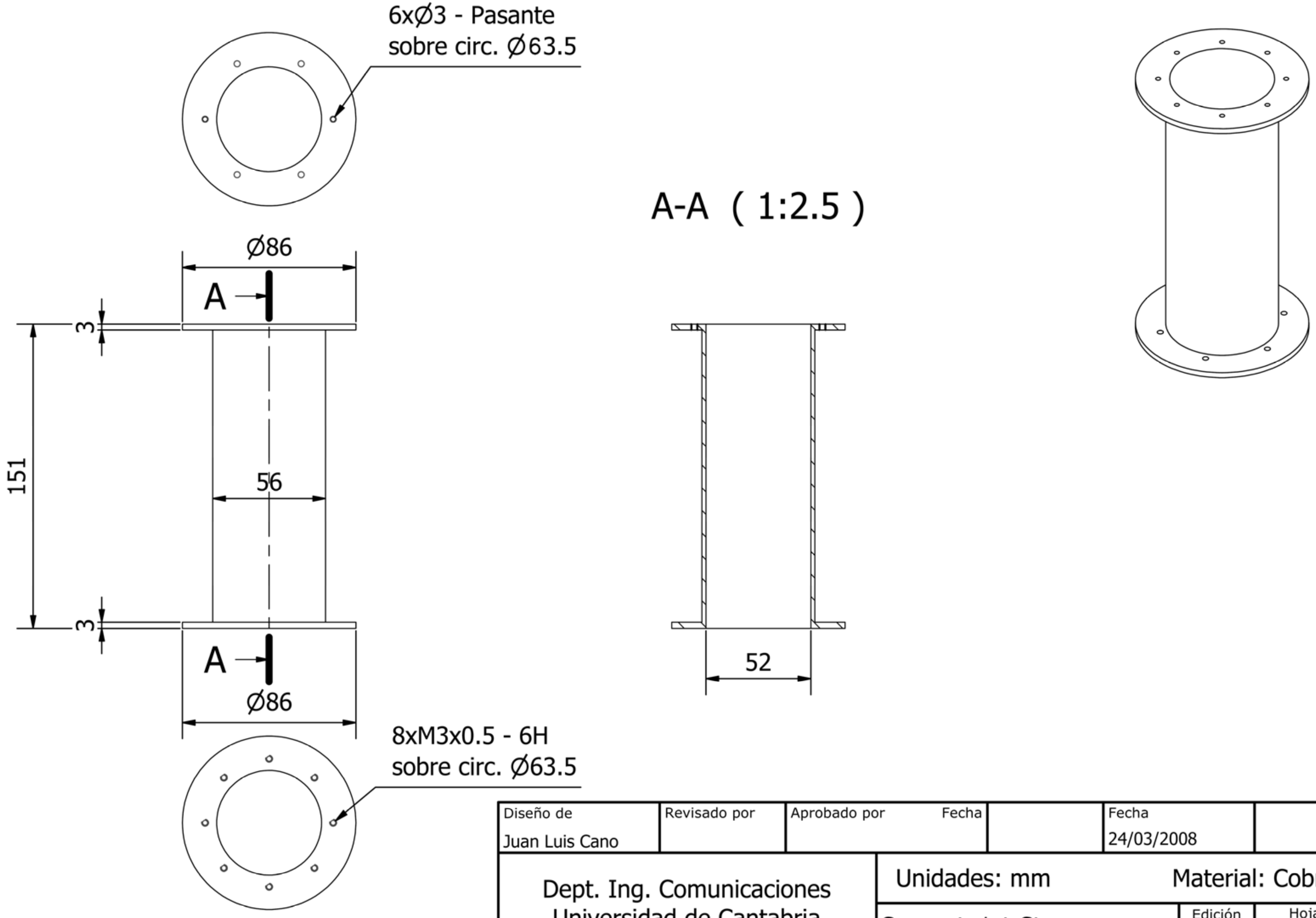
Edición	Hoja
	1 / 1



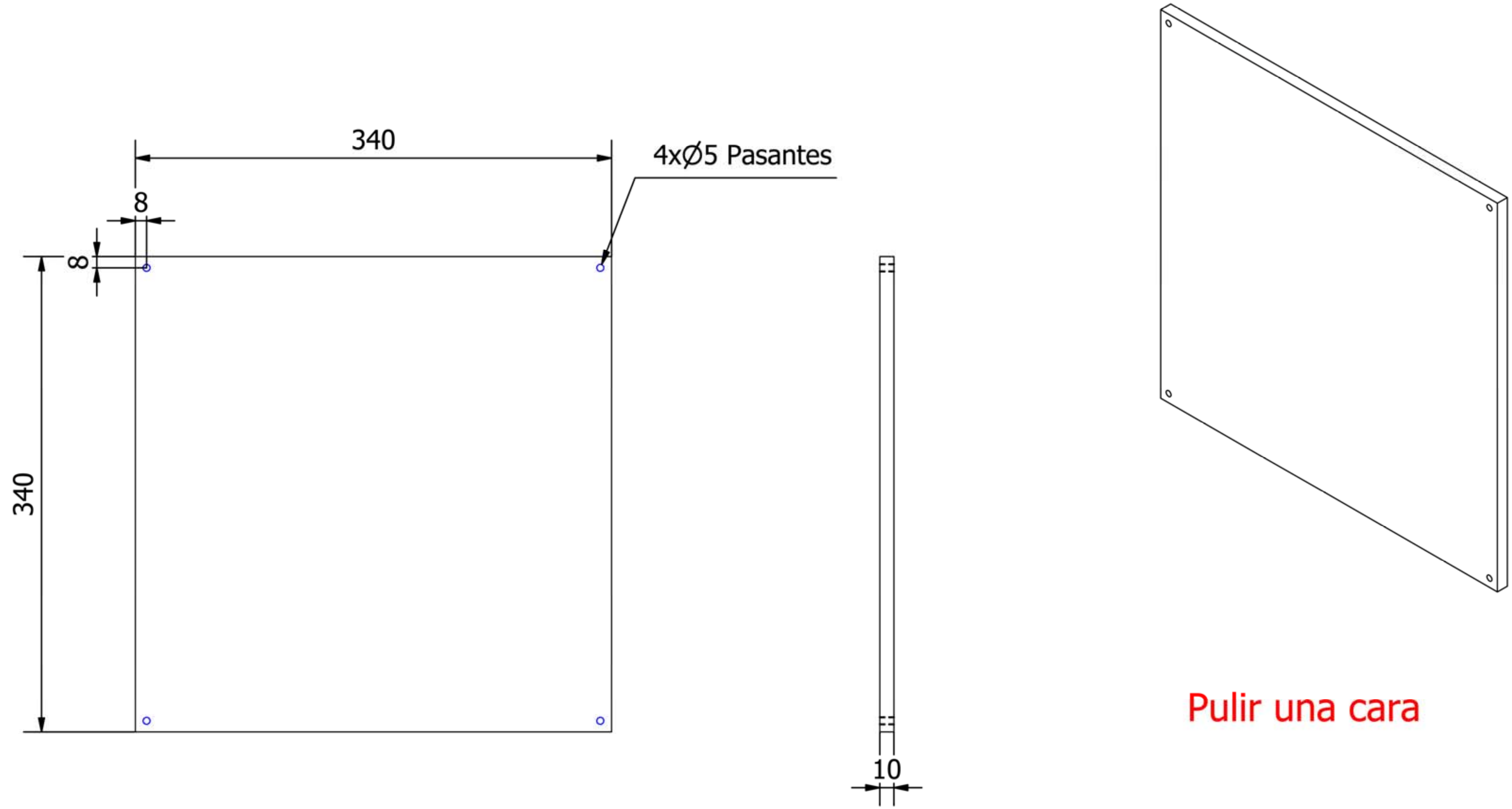
Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				01/04/2008
Dept. Ing. Comunicaciones Universidad de Cantabria	Unidades: mm			Material: Duraluminio
	Dewar		Edición	Hoja 1 / 1



Diseño de	Revisado por	Aprobado por	Fecha	Fecha	
Juan Luis Cano				24/03/2008	
Dept. Ing. Comunicaciones Universidad de Cantabria			Unidades: mm	Material: Duraluminio	
			Support_Dewar	Edición	Hoja 1 / 1

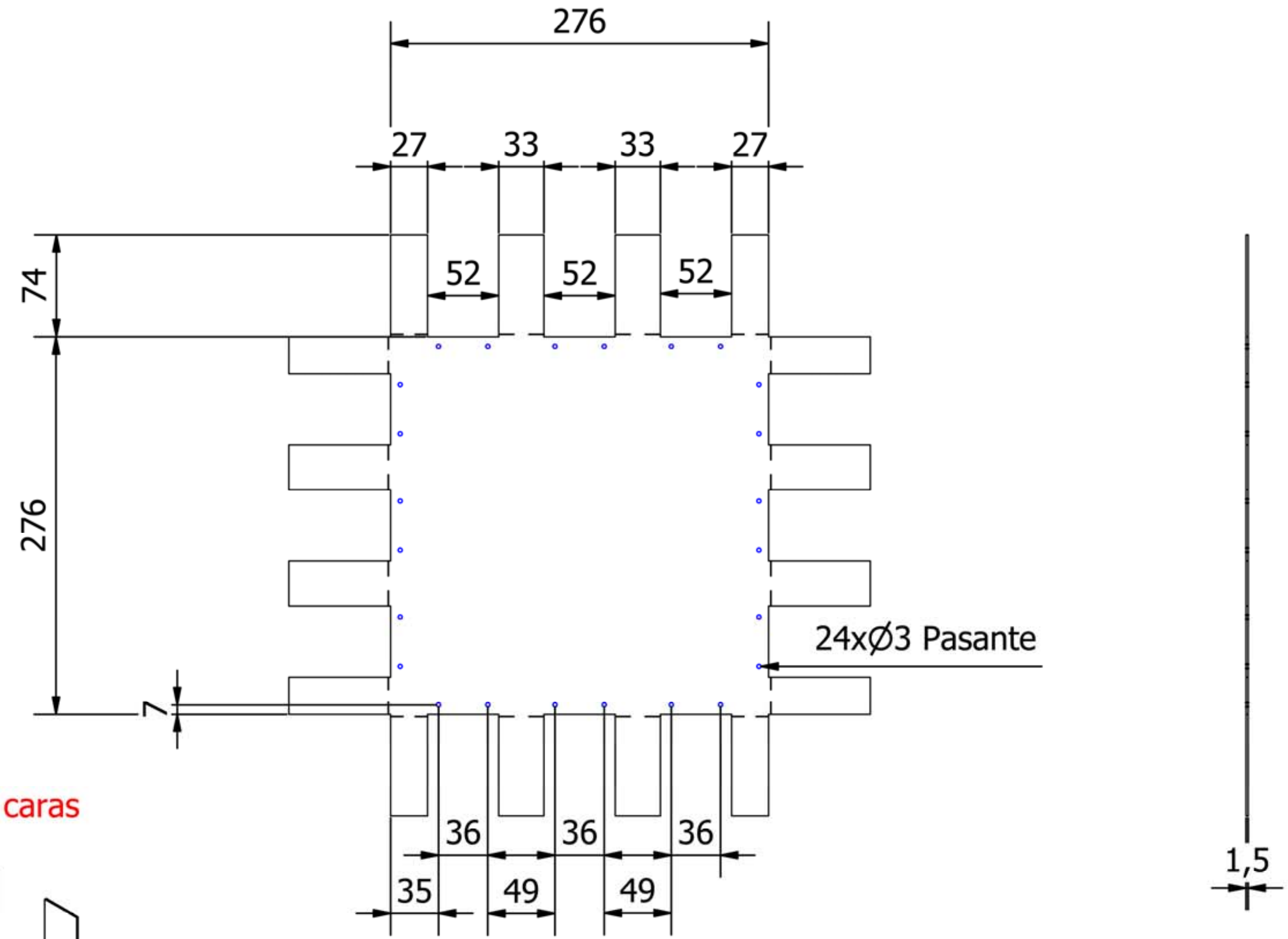


Diseño de Juan Luis Cano	Revisado por	Aprobado por	Fecha	Fecha 24/03/2008	
Dept. Ing. Comunicaciones Universidad de Cantabria		Unidades: mm		Material: Cobre	
		Support_1st-Stage		Edición	Hoja 1 / 1

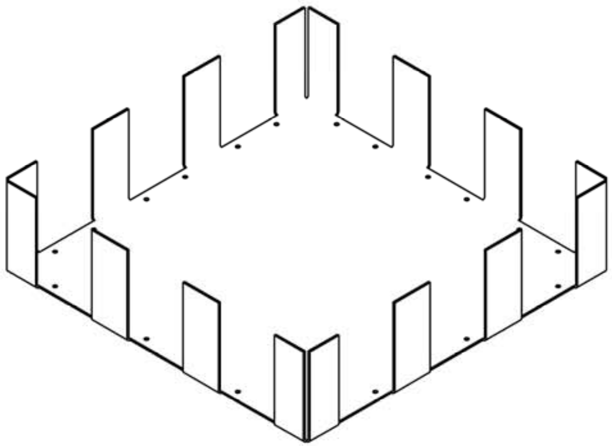


Diseño de	Revisado por	Aprobado por	Fecha	Fecha	
Juan Luis Cano				01/04/2008	

Dept. Ing. Comunicaciones Universidad de Cantabria	Unidades: mm	Material: Duraluminio	
	Dewar_Cover	Edición	Hoja 1 / 1



Pulir ambas caras



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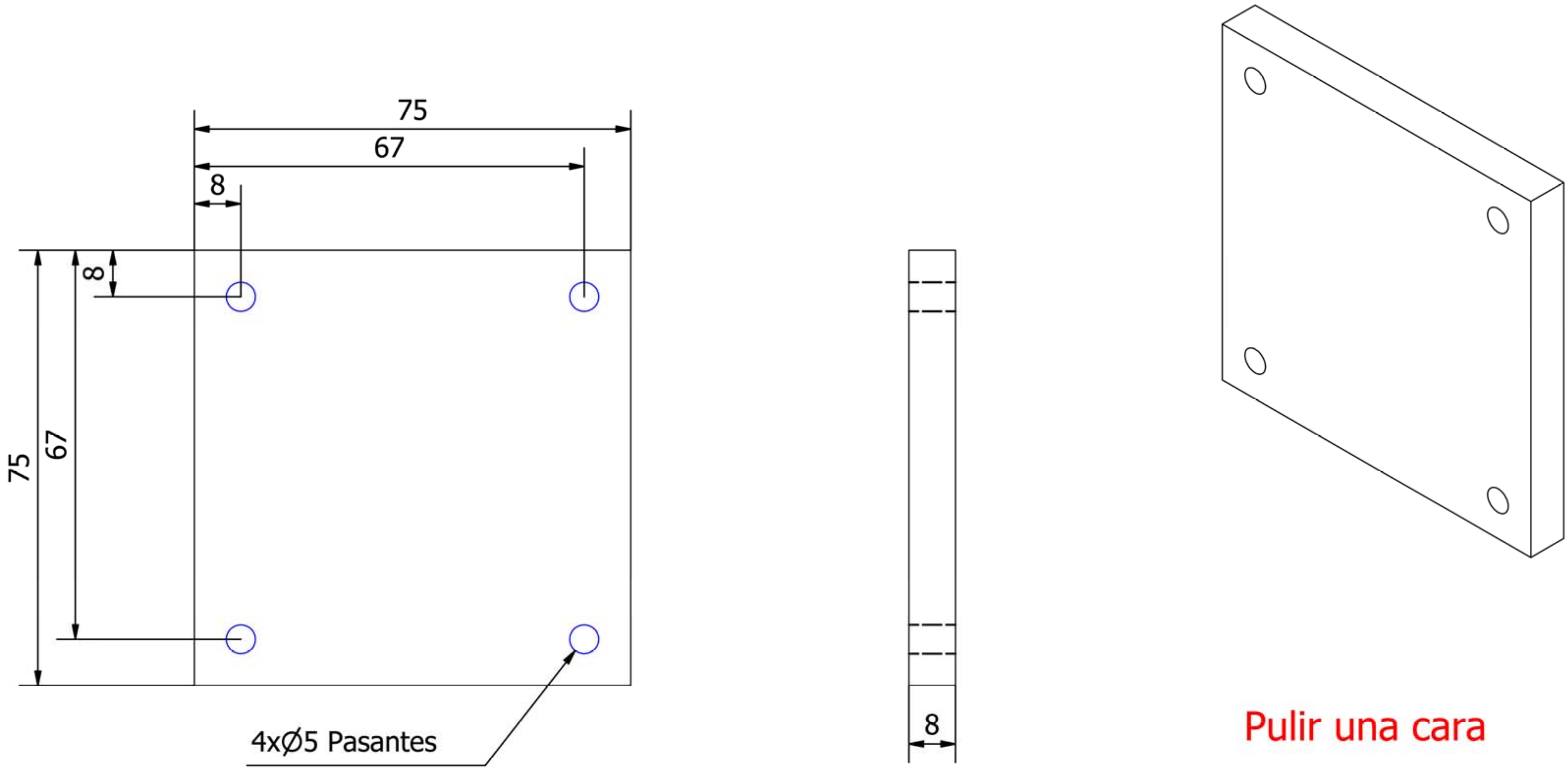
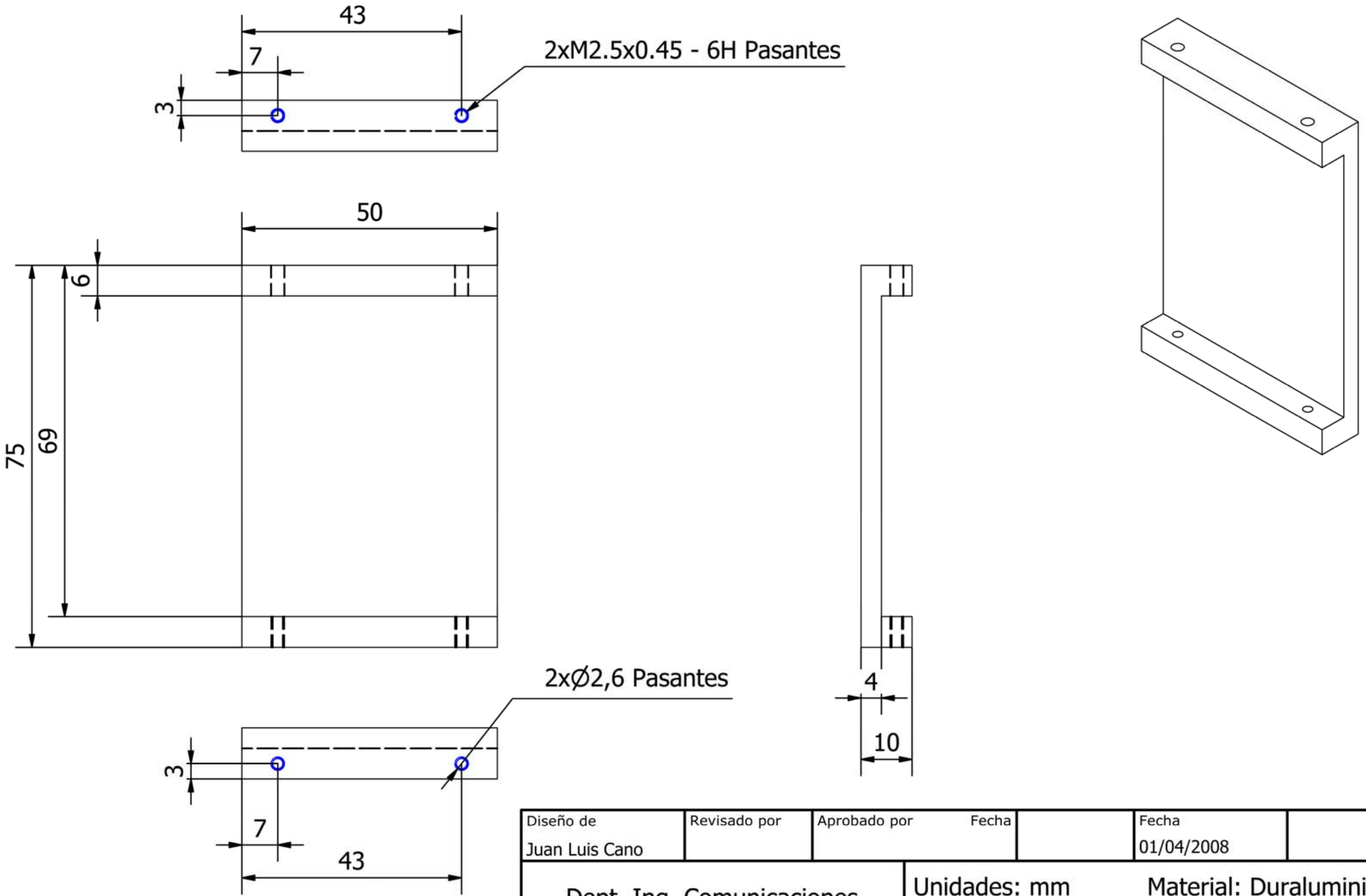
Dept. Ing. Comunicaciones Universidad de Cantabria		Unidades: mm		Material: Aluminio	
		Radiation_Shield		Edición	Hoja 1 / 1

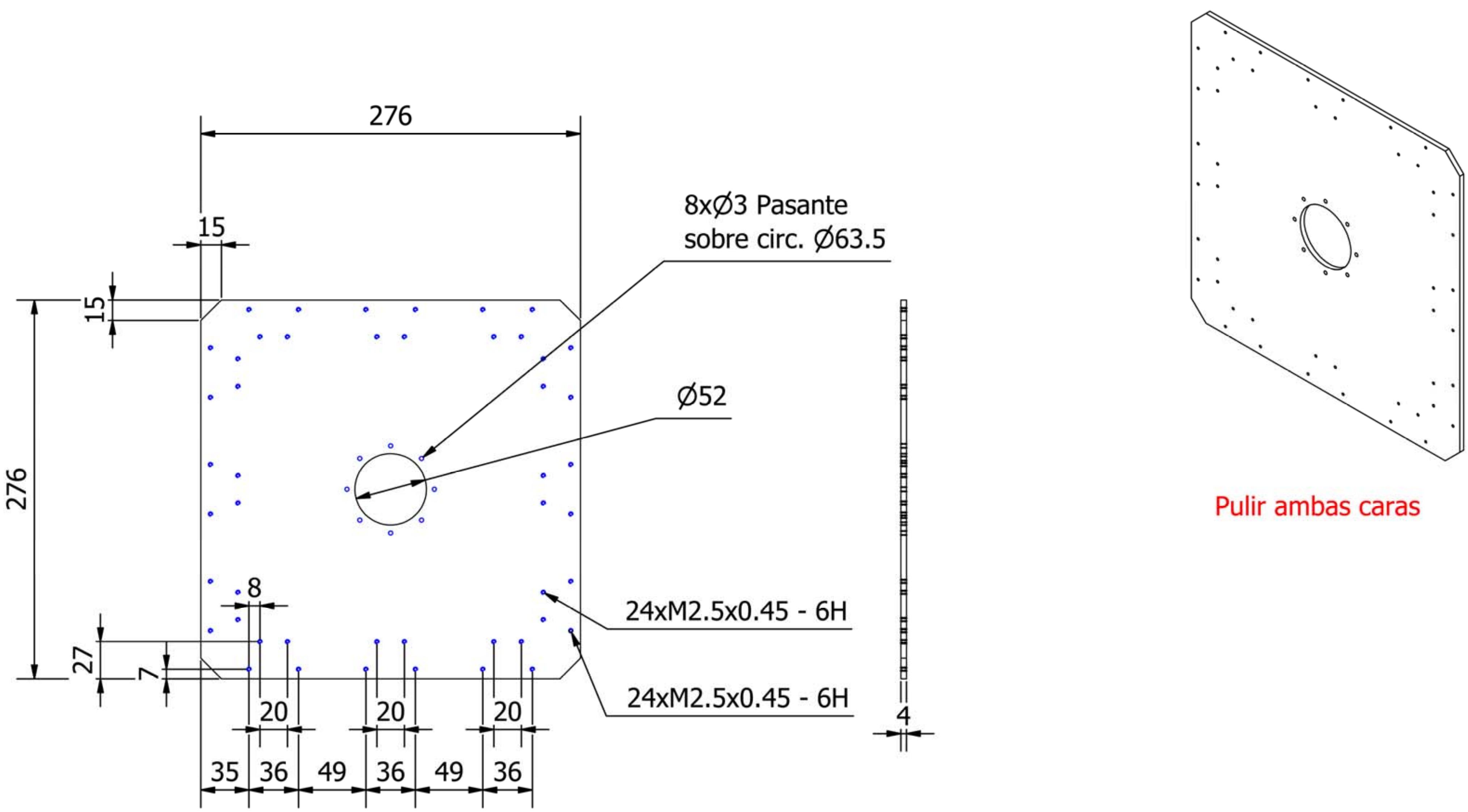


Diseño de Juan Luis Cano	Revisado por	Aprobado por	Fecha	Fecha 01/04/2008	
Dept. Ing. Comunicaciones Universidad de Cantabria		Unidades: mm		Material: Duraluminio	
		Window_Cover		Edición	Hoja 1 / 1



Diseño de	Revisado por	Aprobado por	Fecha		Fecha	
Juan Luis Cano					01/04/2008	

Dept. Ing. Comunicaciones Universidad de Cantabria	Unidades: mm	Material: Duraluminio	
	Rad_Shield_Support	Edición	Hoja 1 / 1



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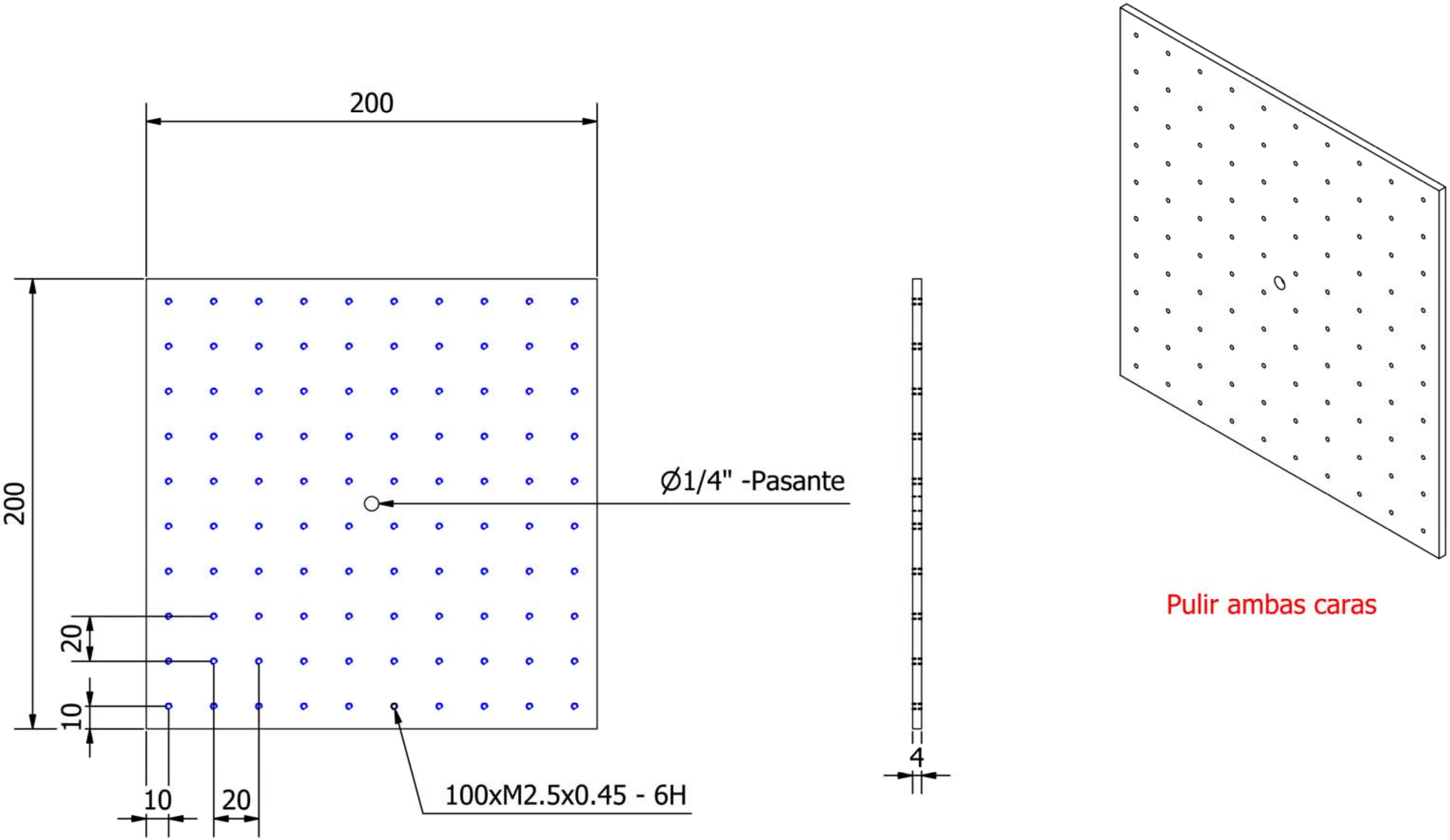
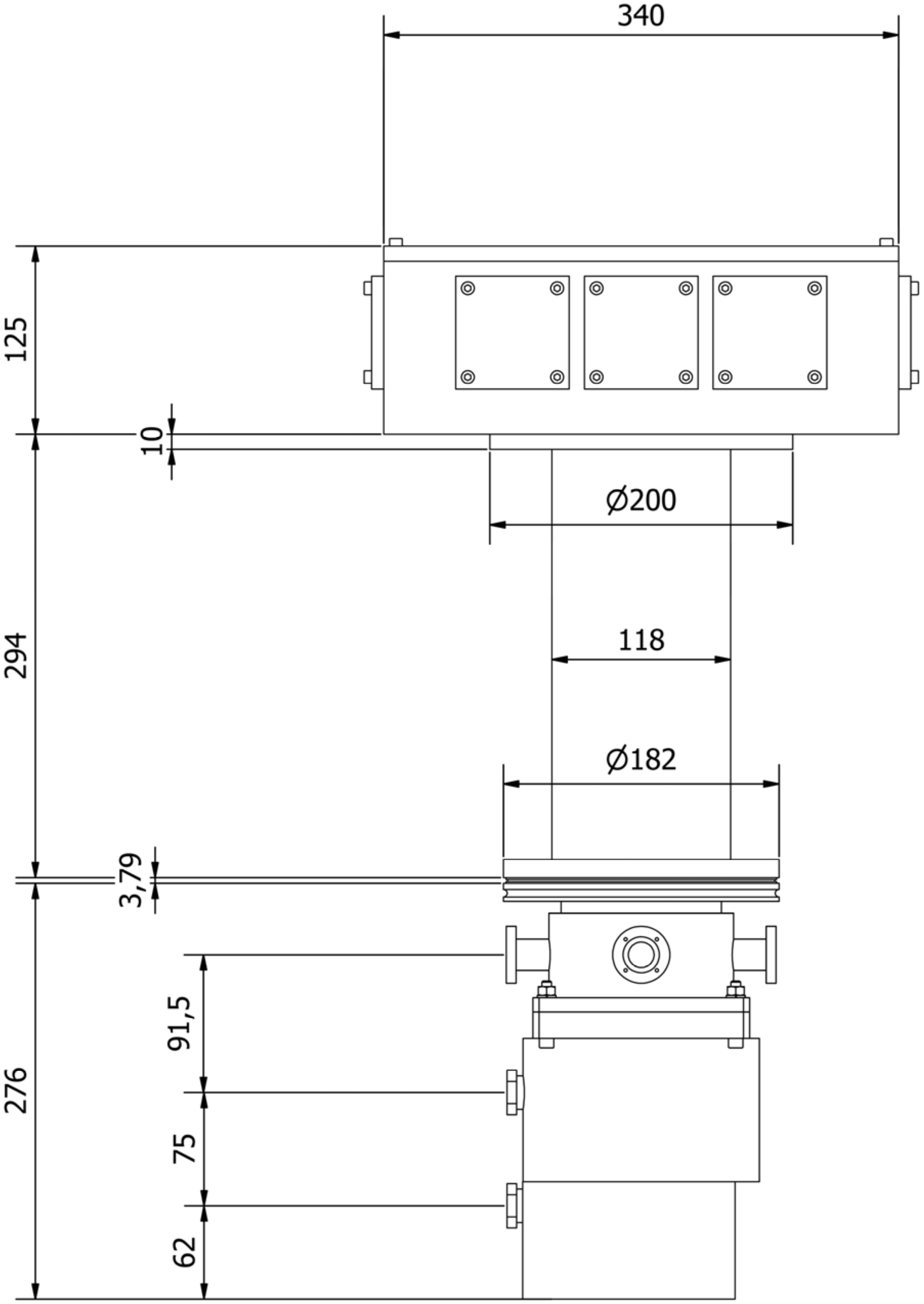
Unidades: mm

Material: Duraluminio

Rad_Shield_Base-1st Stage	Edición	Hoja 1 / 1



Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				24/03/2008
Dept. Ing. Comunicaciones Universidad de Cantabria	Unidades: mm	Material: Duraluminio		
	Cold_Plate-2nd Stage	Edición	Hoja 1 / 1	



Diseño de Juan Luis Cano	Revisado por	Aprobado por	Fecha		Fecha 24/03/2008	
Dept. Ing. Comunicaciones Universidad de Cantabria			Medidas exteriores			
			Contorno		Edición	Hoja 1 / 1

Annex II

Calculation of the Error Terms in the TRL Calibration Technique

A.II.1. Comprehensive Analysis of the 8-Term Error Model

The objective of this study is to obtain the error terms represented in the following figure.

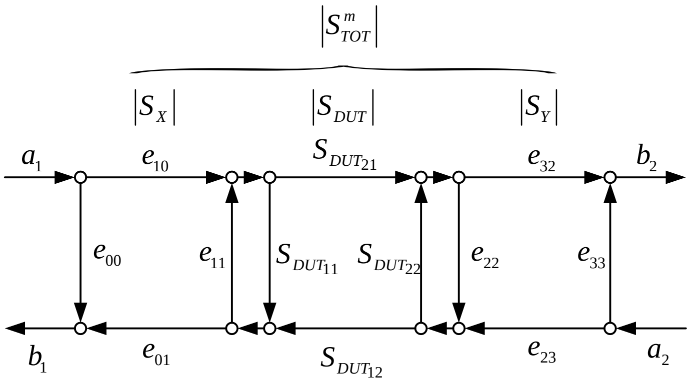


Fig. A.II.1. 8-term error model.

These error terms characterize the test-fixture in the calibration, so they need to be removed in order to calculate the DUT S-parameters at the desired calibration plane. At the beginning of this procedure, four files containing the measurements of the different standards and DUT at calibration plane A (see Fig. 3.3) are available.

- $[S_{TH}^m]$ = Measurement of the Thru standard together with the test-fixture
- $[S_{LN}^m]$ = Measurement of the Line standard together with the test-fixture
- $[S_{RF}^m]$ = Measurement of the Reflect standard together with the test-fixture
- $[S_{TOT}^m]$ = Measurement of the DUT together with the test-fixture

As well as these files, two more data need to be known before the analysis: they are the delays of the Thru and Line standards. In many cases, the Thru has zero length or it is considered like that and therefore the calibration plane is set at the middle of this standard. In order to generalize the problem, here the Thru will be considered with some length so the calibration plane can be set either in the middle of the standard (if the delay is set to zero) or at the standard ports. Usually, this calibration technique with non-zero Thru is called LRL (Line-Reflect-Line) since a Line is used instead of a Thru. As for the length of the Line standard in the TRL technique, it should be $\lambda/4$ longer than the Thru at the central frequency in order to achieve a maximum bandwidth of 8:1 (bandwidth/central frequency). If wider bandwidths are needed then additional Line standards must be used [3.12]

Therefore, together with the four measurement files, these two parameters are needed:

- τ_1 = delay produced by the length of the Thru
- τ_2 = delay produced by the length of the Line

Since the following mathematical analysis works with cascaded S-parameter matrices it is convenient to transform these matrices into transmission parameters using (A.II.1)-(A.II.3) [3.18].

$$\left[S_{TH}^{m}\right]\rightarrow\left[T_{TH}^{m}\right]=\frac{1}{S_{TH21}^{m}}\begin{pmatrix}-\Delta S_{TH}^{m} & S_{TH11}^{m}\\ -S_{TH22}^{m} & 1\end{pmatrix} \quad \text{(A.II.1)}$$

$$\left[S_{LN}^{m}\right]\rightarrow\left[T_{LN}^{m}\right]=\frac{1}{S_{TH21}^{m}}\begin{pmatrix}-\Delta S_{LN}^{m} & S_{LN11}^{m}\\ -S_{LN22}^{m} & 1\end{pmatrix} \quad \text{(A.II.2)}$$

$$\Delta S=S_{11}S_{22}-S_{12}S_{21} \quad \text{(A.II.3)}$$

The S-Parameters of the different standards and the test-fixture are presented in (A.II.4)-(A.II.8).

$$\left[S_{TH}\right]=\begin{pmatrix}0 & e^{-\gamma l_1}\\ e^{-\gamma l_1} & 0\end{pmatrix}\rightarrow\left[T_{TH}\right]=\begin{pmatrix}e^{-\gamma l_1} & 0\\ 0 & e^{\gamma l_1}\end{pmatrix} \quad \text{(A.II.4)}$$

$$\left[S_{LN}\right]=\begin{pmatrix}0 & e^{-\gamma l_2}\\ e^{-\gamma l_2} & 0\end{pmatrix}\rightarrow\left[T_{LN}\right]=\begin{pmatrix}e^{-\gamma l_2} & 0\\ 0 & e^{\gamma l_2}\end{pmatrix} \quad \text{(A.II.5)}$$

$$\left[S_{RF}\right]=\begin{pmatrix}\Gamma_{RF} & 0\\ 0 & \Gamma_{RF}\end{pmatrix} \quad \text{(A.II.6)}$$

$$\left[S_{X}\right]=\begin{pmatrix}e_{00} & e_{01}\\ e_{10} & e_{11}\end{pmatrix} \quad \text{(A.II.7)}$$

$$\left[S_{Y}\right]=\begin{pmatrix}e_{22} & e_{23}\\ e_{32} & e_{33}\end{pmatrix} \quad \text{(A.II.8)}$$

Using the transmission matrices, the measurement of the Thru standard can be easily obtained.

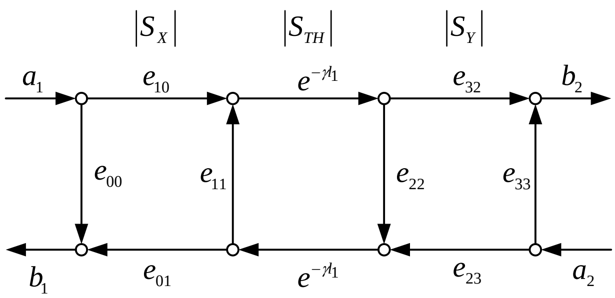


Fig. A.II.2. Measurement of the Thru standard.

$$\left[T_{TH}^{m}\right]=\left[T_{X}\right]\left[T_{TH}\right]\left[T_{Y}\right] \quad \text{(A.II.9)}$$

In a similar way the process can be repeated for the Line standard.

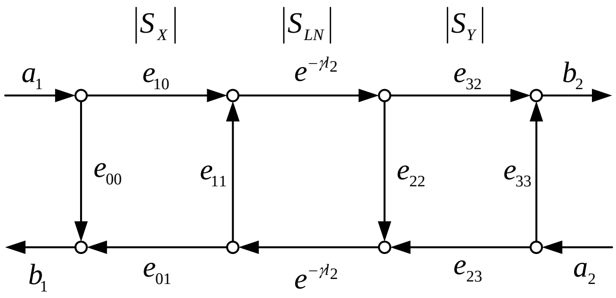


Fig. A.II.3. Measurement of the Line standard.

$$\left[T_{LN}^{m}\right]=\left[T_{X}\right]\left[T_{LN}\right]\left[T_{Y}\right] \quad \text{(A.II.10)}$$

Solving for $[T_Y]$ in (A.II.9),

$$\left[T_{Y}\right]=\left[T_{TH}\right]^{-1}\left[T_{X}\right]^{-1}\left[T_{TH}^{m}\right] \quad \text{(A.II.11)}$$

And now introducing (A.II.11) in (A.II.10),

$$\left[M\right]\left[T_{X}\right]=\left[T_{X}\right]\left[T_{LN}\right]\left[T_{TH}\right]^{-1} \quad \text{(A.II.12)}$$

Where,

$$\left[M\right]=\left[T_{LN}^{m}\right]\left[T_{TH}^{m}\right]^{-1}=\begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \quad \text{(A.II.13)}$$

Expanding equation (A.II.12),

$$\begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}\begin{pmatrix} T_{X11} & T_{X12} \\ T_{X21} & T_{X22} \end{pmatrix}=\begin{pmatrix} T_{X11} & T_{X12} \\ T_{X21} & T_{X22} \end{pmatrix}\begin{pmatrix} e^{-\gamma\Delta l} & 0 \\ 0 & e^{\gamma\Delta l} \end{pmatrix} \quad \text{where } \Delta l = l_2 - l_1 \quad \text{(A.II.14)}$$

The following equations system can be set,

$$m_{11}T_{X11}+m_{12}T_{X21}=T_{X11}e^{-\gamma\Delta l} \quad \text{(A.II.15)}$$

$$m_{21}T_{X11}+m_{22}T_{X21}=T_{X21}e^{-\gamma\Delta l} \quad \text{(A.II.16)}$$

$$m_{11}T_{X12}+m_{12}T_{X22}=T_{X12}e^{\gamma\Delta l} \quad \text{(A.II.17)}$$

$$m_{21}T_{X12}+m_{22}T_{X22}=T_{X22}e^{\gamma\Delta l} \quad \text{(A.II.18)}$$

The term $e^{-\gamma\Delta l}$ can be eliminated from (A.II.15) and (A.II.16), obtaining,

$$m_{21}\left(\frac{T_{X11}}{T_{X21}}\right)^2+(m_{22}-m_{11})\left(\frac{T_{X11}}{T_{X21}}\right)-m_{12}=0 \qquad \text{(A.II.19)}$$

And eliminating the term $e^{\gamma\Delta l}$ from (A.II.17) and (A.II.18),

$$m_{21}\left(\frac{T_{X12}}{T_{X22}}\right)^2+(m_{22}-m_{11})\left(\frac{T_{X12}}{T_{X22}}\right)-m_{12}=0 \qquad \text{(A.II.20)}$$

Both equations (A.II.19) and (A.II.20) have the same coefficients and therefore they have the same roots,

$$\left(\frac{T_{X11}}{T_{X21}}\right)=a=\frac{\Delta S_X}{e_{11}} \qquad \text{(A.II.21)}$$

$$\left(\frac{T_{X12}}{T_{X22}}\right)=b=e_{00} \qquad \text{(A.II.22)}$$

In order to assign correctly the equation roots to the variables in the previous equations it is necessary to consider the following relationship,

$$|e_{00}|<<\left|\frac{\Delta S_X}{e_{11}}\right| \qquad \text{(A.II.23)}$$

A similar procedure can be followed in the output access to obtain its parameters. Thus, solving for $[T_X]$ in (A.II.9),

$$[T_X]=[T_{TH}^m][T_Y]^{-1}[T_{TH}]^{-1} \qquad \text{(A.II.24)}$$

And now introducing (A.II.24) in (A.II.10),

$$[T_Y][N]=[T_{TH}]^{-1}[T_{LN}][T_Y] \qquad \text{(A.II.25)}$$

Expanding (A.II.25),

$$\begin{pmatrix} T_{Y11} & T_{Y12} \\ T_{Y21} & T_{Y22} \end{pmatrix}\begin{pmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{pmatrix}=\begin{pmatrix} e^{-\gamma\Delta l} & 0 \\ 0 & e^{\gamma\Delta l} \end{pmatrix}\begin{pmatrix} T_{Y11} & T_{Y12} \\ T_{Y21} & T_{Y22} \end{pmatrix} \qquad \text{(A.II.26)}$$

An equations system can be set again,

$$n_{11}T_{Y11}+n_{12}T_{Y12}=T_{Y11}e^{-\gamma\Delta l} \qquad \text{(A.II.27)}$$

$$n_{12}T_{Y11}+n_{22}T_{Y12}=T_{Y12}e^{-\gamma\Delta l} \qquad \text{(A.II.28)}$$

$$n_{11}T_{Y21} + n_{21}T_{Y22} = T_{Y21}e^{\gamma\Delta l} \quad \text{(A.II.29)}$$

$$n_{12}T_{Y21} + n_{22}T_{Y22} = T_{Y22}e^{\gamma\Delta l} \quad \text{(A.II.30)}$$

Solving this system in the same way the following two equations are obtained,

$$n_{12}\left(\frac{T_{Y11}}{T_{Y12}}\right)^2 + (n_{22} - n_{11})\left(\frac{T_{Y11}}{T_{Y12}}\right) - n_{21} = 0 \quad \text{(A.II.31)}$$

$$n_{12}\left(\frac{T_{Y21}}{T_{Y22}}\right)^2 + (n_{22} - n_{11})\left(\frac{T_{Y21}}{T_{Y22}}\right) - n_{21} = 0 \quad \text{(A.II.32)}$$

These equations have the same roots which are,

$$\left(\frac{T_{Y11}}{T_{Y12}}\right) = c = \frac{-\Delta S_Y}{e_{22}} \quad \text{(A.II.33)}$$

$$\left(\frac{T_{Y21}}{T_{Y22}}\right) = d = -e_{33} \quad \text{(A.II.34)}$$

And now again, the selection of the roots made above is straightforward if the following relationship is considered,

$$|e_{33}| << \left|\frac{\Delta S_Y}{e_{22}}\right| \quad \text{(A.II.35)}$$

By now, the terms e_{00} and e_{33} and the relationships $\frac{\Delta S_X}{e_{11}}$ and $\frac{\Delta S_Y}{e_{22}}$ have been obtained. As well as these, the term of propagation in the lines, $\gamma\Delta l$, can be calculated just introducing the obtained terms in one of the equations in (A.II.15)-(A.II.18) or (A.II.27)-(A.II.30).

$$W = e^{\gamma\Delta l} = m_{11} + \frac{m_{12}}{e_{00}} \quad \text{(A.II.36)}$$

To obtain the remaining terms it is necessary to use the measurement of the Reflect standard from both ports.

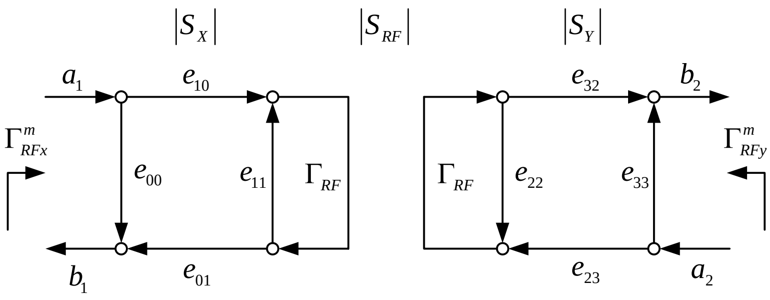


Fig. A.II.4. Measurement of the Reflect standard.

In order to calculate the measured reflection coefficient in one port regarding the actual reflection coefficient of the standard, the flow graph of Fig. A.II.4 has to be solved [3.19], [3.20].

$$\Gamma^m_{RFx} = S^m_{RF11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = e_{00} + \frac{e_{01}e_{10}}{\dfrac{1}{\Gamma_{RF}} - e_{11}} \quad \text{(A.II.37)}$$

$$\Gamma^m_{RFy} = S^m_{RF22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} = e_{33} + \frac{e_{23}e_{32}}{\dfrac{1}{\Gamma_{RF}} - e_{22}} \quad \text{(A.II.38)}$$

Solving for $1/\Gamma_{RF}$ in both equations a relationship between e_{11} and e_{22} can be extracted.

$$e_{11}\left(1+\frac{X}{A}\right) = e_{22}\left(1+\frac{Y}{B}\right) \quad \text{(A.II.39)}$$

Where,

$$X = \frac{e_{01}e_{10}}{e_{11}} \quad \text{(A.II.40)}$$

$$Y = \frac{e_{23}e_{32}}{e_{22}} \quad \text{(A.II.41)}$$

$$A = \Gamma^m_{RFx} - e_{00} \quad \text{(A.II.42)}$$

$$B = \Gamma^m_{RFy} - e_{33} \quad \text{(A.II.43)}$$

Taking into account that $X = b - a$ and $Y = c - d$, then the values of (A.II.40)-(A.II-43) are known. To obtain another relationship between e_{11} and e_{22} enabling to calculate their values it is necessary to use the measurement of the reflection coefficient at the Thru standard input.

From the flow graph of Fig. A.II.2,

$$\Gamma_{THx}^{m} = S_{TH11}^{m} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = e_{00} + \frac{e_{01}e_{10}e_{22}e^{-2\gamma l_1}}{1 - e_{11}e_{22}e^{-2\gamma l_1}} \tag{A.II.44}$$

And therefore,

$$C = S_{TH11}^{m} - e_{00} = \frac{e_{01}e_{10}e_{22}e^{-2\gamma l_1}}{1 - e_{11}e_{22}e^{-2\gamma l_1}} \tag{A.II.45}$$

Introducing (A.II.39) in (A.II.45),

$$e_{11}e_{22}e^{-2\gamma l_1} = \left(1 + \frac{X}{C}\right)^{-1} \tag{A.II.46}$$

Now two equations are available so e_{11} and e_{22} can be calculated.

$$e_{22} = \pm e^{\gamma l_1}\left[\left(1 + \frac{X}{A}\right)\left(1 + \frac{Y}{B}\right)^{-1}\left(1 + \frac{X}{C}\right)^{-1}\right]^{\frac{1}{2}} \tag{A.II.47}$$

$$e_{11} = e_{22}\left(1 + \frac{Y}{B}\right)\left(1 + \frac{X}{A}\right)^{-1} \tag{A.II.48}$$

In order to solve (A.II.47) the value of $e^{\gamma l_1}$ need to be known. This value can be extracted from the known data if (A.II.36) is conveniently transformed.

$$e^{\gamma l_1} = \left(e^{\gamma(l_2 - l_1)}\right)^{\left(\frac{l_2}{l_1} - 1\right)^{-1}} = W^{\left(\frac{\tau_2}{\tau_1} - 1\right)^{-1}} \tag{A.II.49}$$

Once this value is calculated, the right root must be selected in (A.II.47). This can be achieved through the knowledge of the Reflect standard phase. The values calculated in (A.II.47) and (A.II.48) can be introduced in (A.II.37) and this equation can be solved for the actual reflection coefficient of the Reflect regarding its measured value.

$$\Gamma_{RF} = \frac{1}{e_{11}}\frac{b - \Gamma_{RFx}^{m}}{a - \Gamma_{RFx}^{m}} \tag{A.II.50}$$

A good Reflect standard should have a reflection coefficient magnitude large (ideally 1.0), equal in both ports, and its phase has to be defined with an accuracy of $\pm\lambda/4$ [3.12]. When the two solutions of (A.II.47) are introduced in (A.II.50) then two reflection coefficients 180º out of phase are obtained, therefore the selection of the right root is obvious.

Now the calculation of the remaining terms can be continued.

$$e_{01}e_{10} = e_{11}X \tag{A.II.51}$$

$$e_{23}e_{32} = e_{22}Y \tag{A.II.52}$$

The transmission coefficients in (A.II.51) and (A.II.52) do not need to be known separately so the calculation process is simplified.

Finally, with the derivation of the transmission S-Parameters of Fig. A.II.2,

$$S^m_{TH21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} = \frac{e_{10}e_{32}e^{-\gamma l_1}}{1-e_{11}e_{22}e^{-2\gamma l_1}} \tag{A.II.53}$$

$$S^m_{TH12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} = \frac{e_{01}e_{23}e^{-\gamma l_1}}{1-e_{11}e_{22}e^{-2\gamma l_1}} \tag{A.II.54}$$

The last term products can be obtained.

$$e_{10}e_{32} = e^{\gamma l_1}S^m_{TH21}\left(1-\frac{e_{11}e_{22}}{e^{2\gamma l_1}}\right) \tag{A.II.55}$$

$$e_{01}e_{23} = e^{\gamma l_1}S^m_{TH12}\left(1-\frac{e_{11}e_{22}}{e^{2\gamma l_1}}\right) \tag{A.II.56}$$

Now the calculation of the different error terms is completed and the DUT S-Parameters, with the calibration plane set at its ports, are obtained with (A.II.57)-(A.II.60).

$$S_{DUT11} = \frac{e_{22}S^m_{TOT12}S^m_{TOT21} + \left(e_{00} - S^m_{TOT11}\right)\left(e_{22}S^m_{TOT22} - \Delta S_Y\right)}{D} \tag{A.II.57}$$

$$S_{DUT22} = \frac{e_{11}S^m_{TOT12}S^m_{TOT21} + \left(e_{33} - S^m_{TOT22}\right)\left(e_{11}S^m_{TOT11} - \Delta S_X\right)}{D} \tag{A.II.58}$$

$$S_{DUT12} = \frac{-e_{10}e_{32}S^m_{TOT12}}{D} \tag{A.II.59}$$

$$S_{DUT21} = \frac{-e_{01}e_{23}S^m_{TOT21}}{D} \tag{A.II.60}$$

Where,

$$D = e_{11}e_{22}S^m_{TOT12}S^m_{TOT21} - \left(e_{11}S^m_{TOT11} - \Delta S_X\right)\left(e_{22}S^m_{TOT22} - \Delta S_Y\right) \tag{A.II.61}$$

$$\Delta S_X = e_{00}e_{11} - e_{01}e_{10} \tag{A.II.62}$$

$$\Delta S_Y = e_{22}e_{33} - e_{23}e_{32} \tag{A.II.63}$$

A.II.2. Correction of Switch Errors

In Chapter 3 it was commented that the 8-term error model can not fully characterize the errors produced in a two-port network such as the network analyzer, since it can not take into account the different impedances of the internal switch in its different states. This is not a problem in the technique proposed in this thesis since the network analyzer is calibrated with a SOLT technique before the measurement of each standard and therefore the errors are only present in the test-fixture, which is fully characterized with an 8-term model. However, in order to complete the previous study, a short explanation of how modern network analyzers solve this problem is given here.

Modern network analyzers, such as model 8510C from Agilent Technologies, have an architecture with a receiver equipped with four samplers and therefore they can measure the ratio between the two reference signals during the measurement of the Thru and Line standards. These measurements characterize the switch impedance and its associated hardware both forward and reverse [3.21].

To characterize the difference between switch states the system has to correct the measured S-Parameters, which needs to take six measurements instead of four for each of these standards. Thus, the measured S-Parameters can be expressed as [3.13],

$$S^m = \begin{pmatrix} b_1 & b_1^{'} \\ b_2 & b_2^{'} \end{pmatrix} \begin{pmatrix} a_1 & a_1^{'} \\ a_2 & a_2^{'} \end{pmatrix}^{-1} \quad \text{(A.II.64)}$$

Where the prime terms indicate that the switch is in reverse. Expanding the previous expression the different S-Parameters are obtained.

$$S_{11}^m = \frac{\frac{b_1}{a_1} - \frac{b_1^{'}}{a_2^{'}} \frac{a_2}{a_1}}{\Delta} \quad \text{(A.II.65)}$$

$$S_{12}^m = \frac{\frac{b_1^{'}}{a_2^{'}} - \frac{b_1}{a_1} \frac{a_1^{'}}{a_2^{'}}}{\Delta} \quad \text{(A.II.66)}$$

$$S_{21}^m = \frac{\frac{b_2}{a_1} - \frac{b_2^{'}}{a_2^{'}} \frac{a_2}{a_1}}{\Delta} \quad \text{(A.II.67)}$$

$$S_{22}^m = \frac{\frac{b_2^{'}}{a_2^{'}} - \frac{b_2}{a_1} \frac{a_1^{'}}{a_2^{'}}}{\Delta} \quad \text{(A.II.68)}$$

Where,

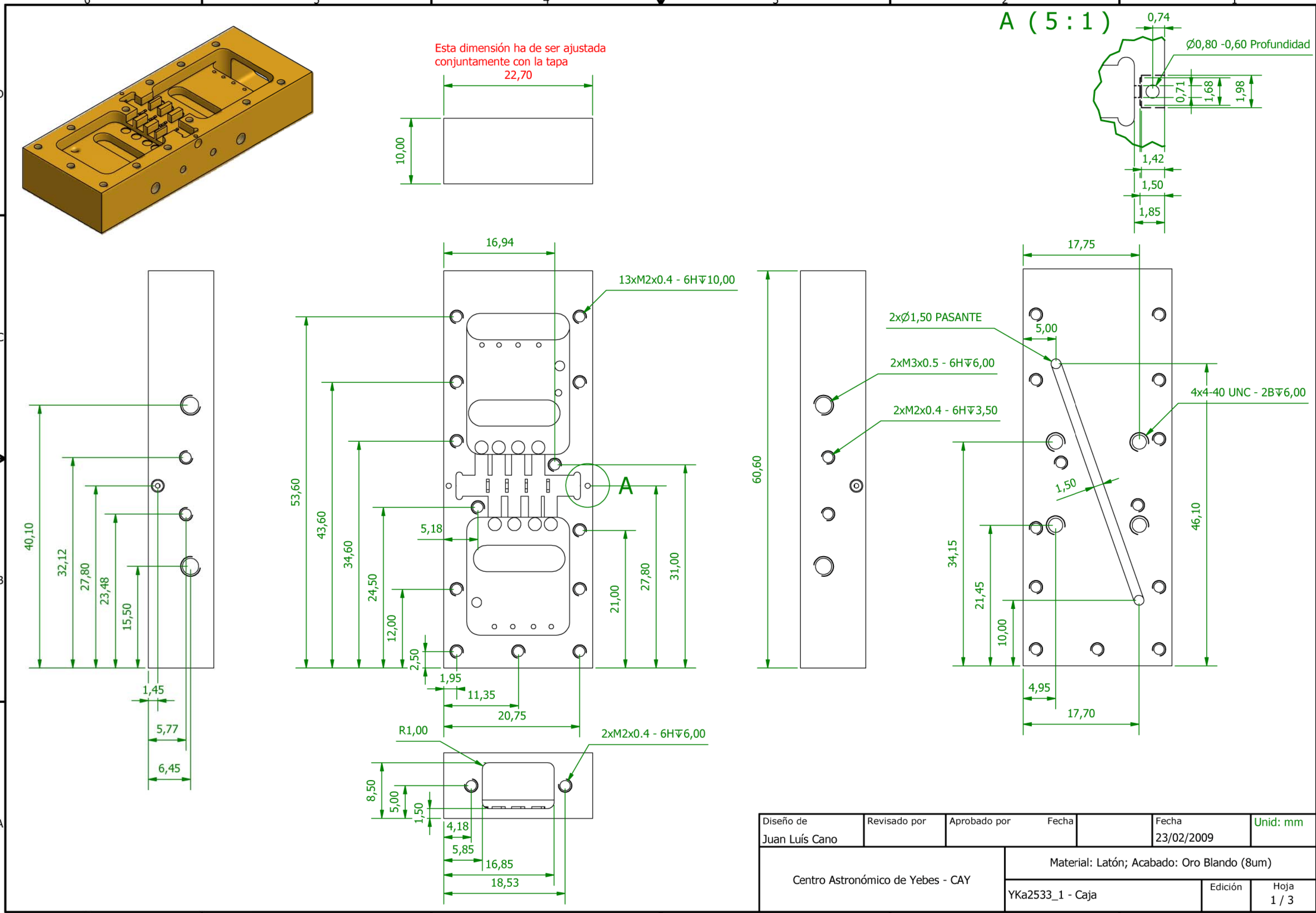
$$\Delta = 1 - \frac{a_2}{a_1}\frac{a_1^{'}}{a_2^{'}} \tag{A.II.69}$$

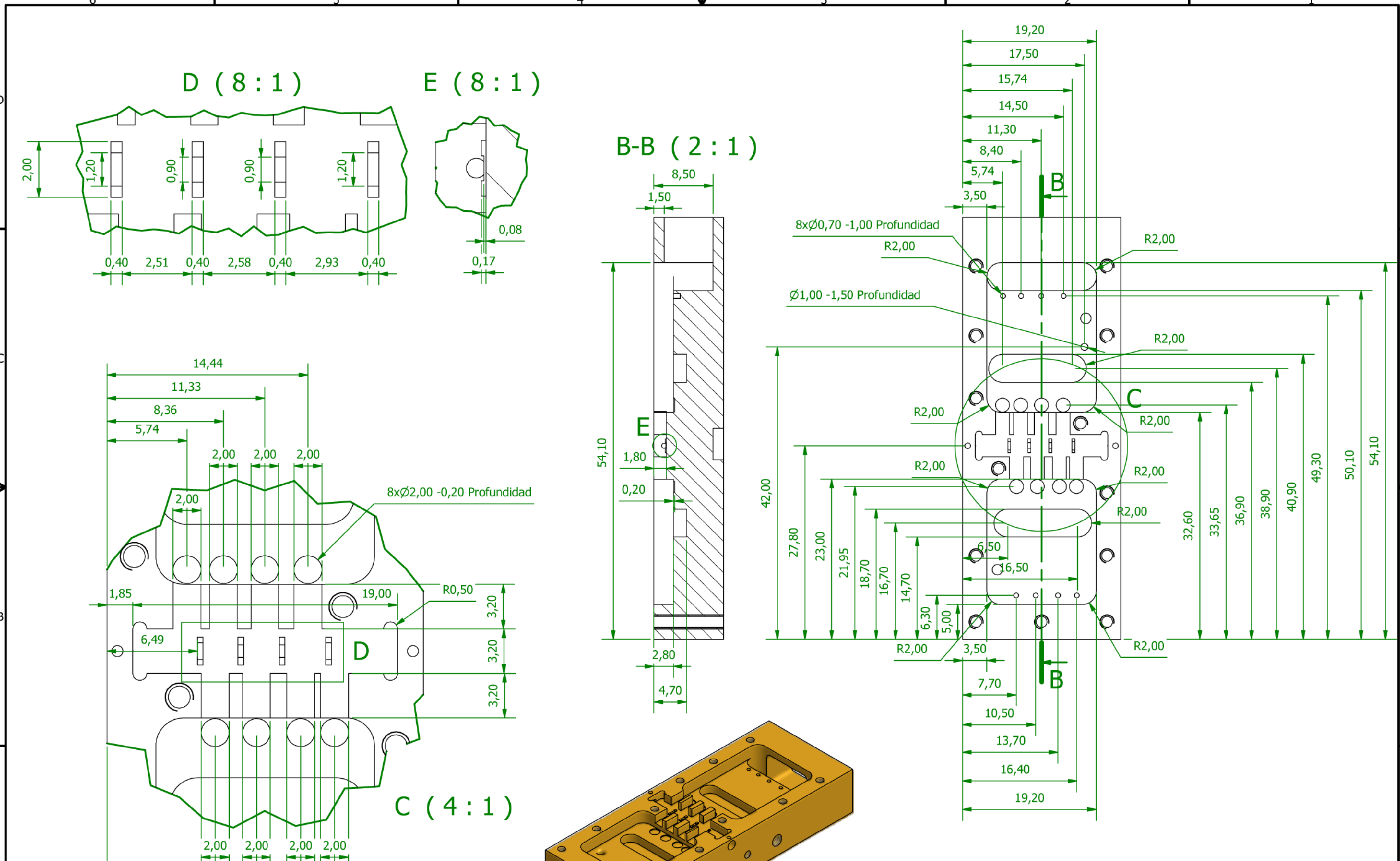
As can be seen in (A.II.65)-(A.II.69), to correct the S-Parameters two additional measurements are needed for the standards.

Annex III

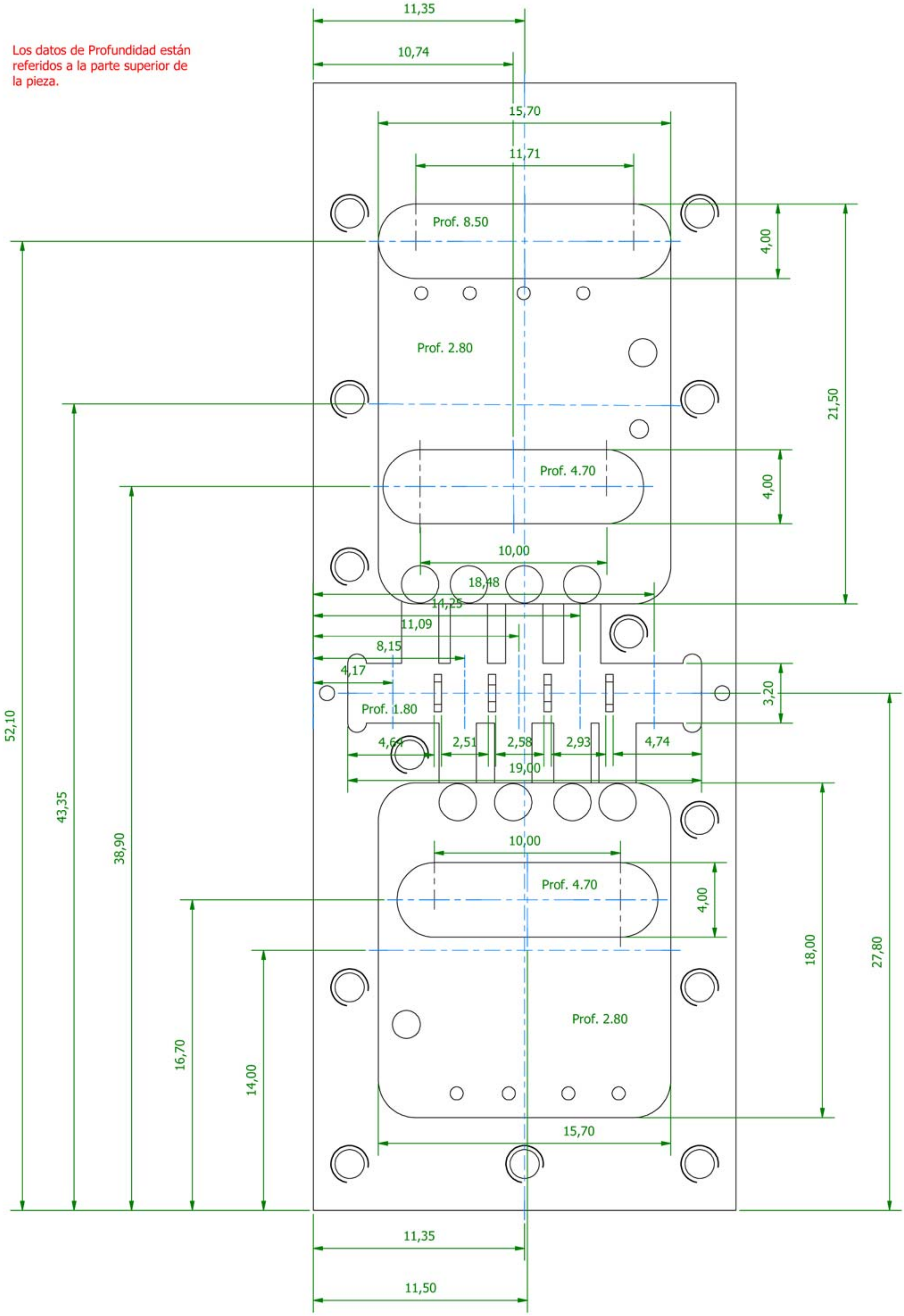
MIC LNA Module Drawings

No.	Drawing Name	Description
1	YKa2533_1 – Caja 1/3	Module holes
2	YKa2533_1 – Caja 2/3	Module dimensions
3	YKa2533_1 – Caja 3/3	Module depths
4	YKa2533_1 – Tapa	Module normal lid
5	YKa2533_1 – Caja_LEDs	Module lid adapted for illuminating LEDs
6	YKa2533_1 – Acceso Guía	Module waveguide port
7	YKa2533_1 – Adaptador	Waveguide-to-coaxial transition adapter
8	YKa2533_1 – Componentes 1/2	RF Components installation
9	YKa2533_1 – Componentes 2/2	Bias components installation
10	YKa2533_1 – Dispositivos	Components general view
11	YKa2533_1 – LNA	Artist view of the assembly
12	YKa2533_1 – Montaje	Part list and assembly procedure


A (5 : 1)
0,74
Ø0,80 -0,60 Profundidad
0,71
1,68
1,98
1,42
1,50
1,85
Esta dimensión ha de ser ajustada
conjuntamente con la tapa
22,70
10,00
16,94
13xM2x0.4 - 6H↧10,00
53,60
43,60
34,60
24,50
12,00
5,18
2,50
1,95
11,35
20,75
21,00
27,80
31,00
A
40,10
32,12
27,80
23,48
15,50
1,45
5,77
6,45
R1,00
2xM2x0.4 - 6H↧6,00
8,50
5,00
1,50
4,18
5,85
16,85
18,53
60,60
2xØ1,50 PASANTE
2xM3x0.5 - 6H↧6,00
2xM2x0.4 - 6H↧3,50
17,75
5,00
4x4-40 UNC - 2B↧6,00
1,50
46,10
34,15
21,45
10,00
4,95
17,70
Diseño de
Juan Luís Cano
Revisado por
Aprobado por
Fecha
Fecha
23/02/2009
Unid: mm
Centro Astronómico de Yebes - CAY
Material: Latón; Acabado: Oro Blando (8um)
YKa2533_1 - Caja
Edición
Hoja
1 / 3

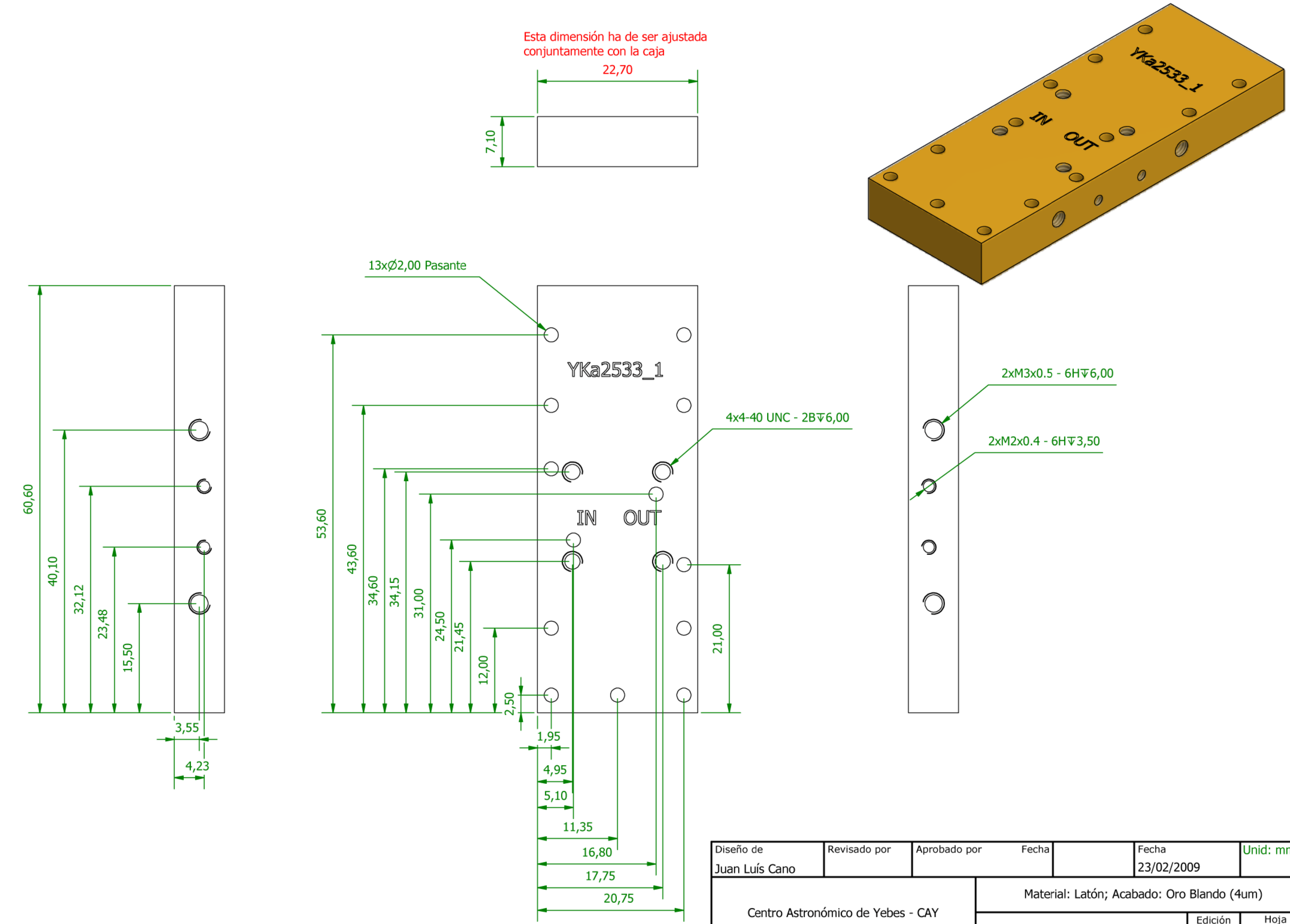


Diseño de	Revisado por	Aprobado por	Fecha	Fecha	Unid: mm
Juan Luís Cano				23/02/2009	
Centro Astronómico de Yebes - CAY		Material: Latón; Acabado: Oro Blando (8um)			
		YKa2533_1 - Caja		Edición	Hoja 2 / 3

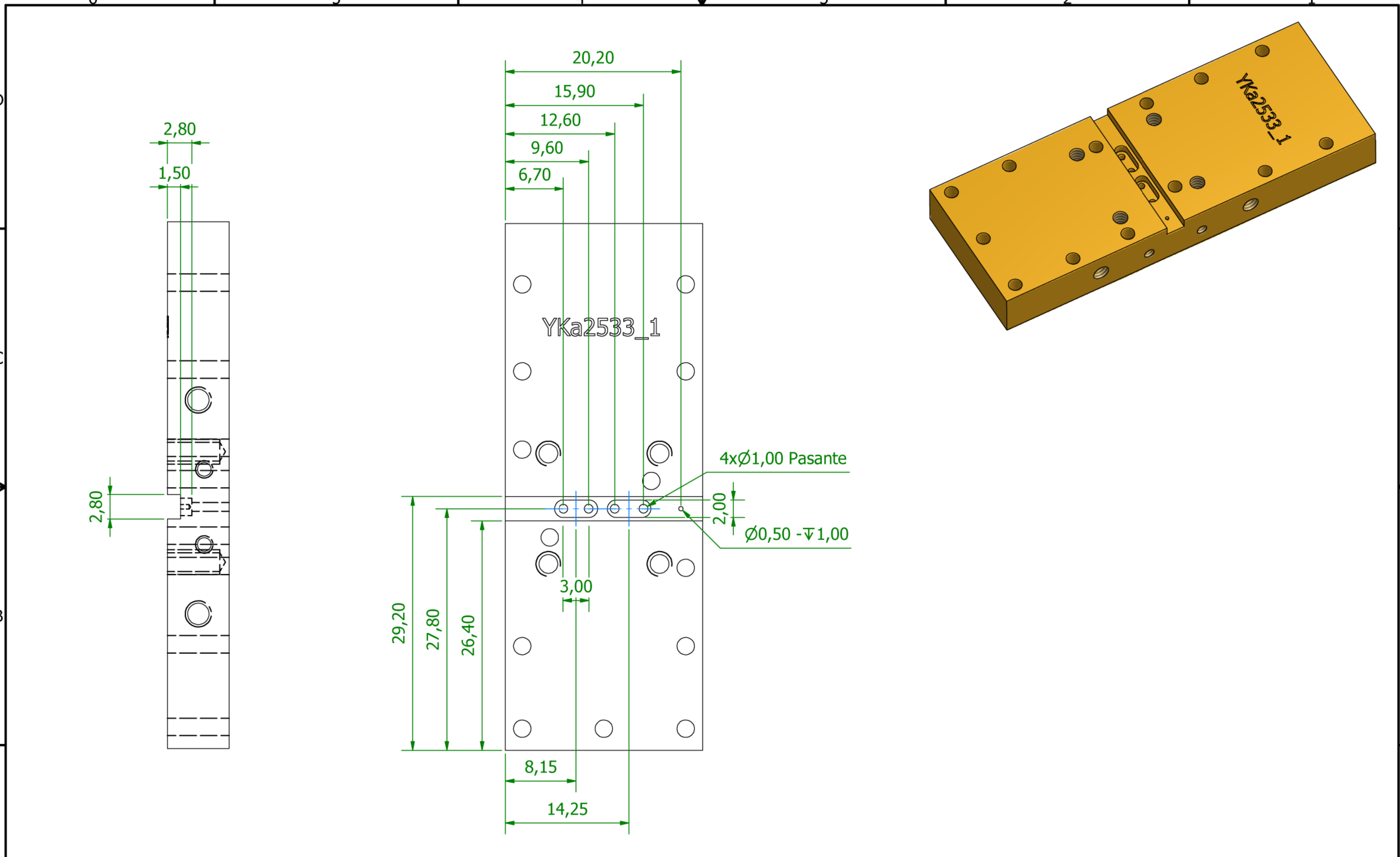


Los datos de Profundidad están referidos a la parte superior de la pieza.

Diseño de	Revisado por	Aprobado por	Fecha		Fecha	
Juan Luís Cano					23/02/2009	
Centro Astronómico de Yebes - CAY			Material: Latón; Acabado: Oro Blando (8um)			
			YKa2533_1 - Caja		Edición	Hoja 3 / 3

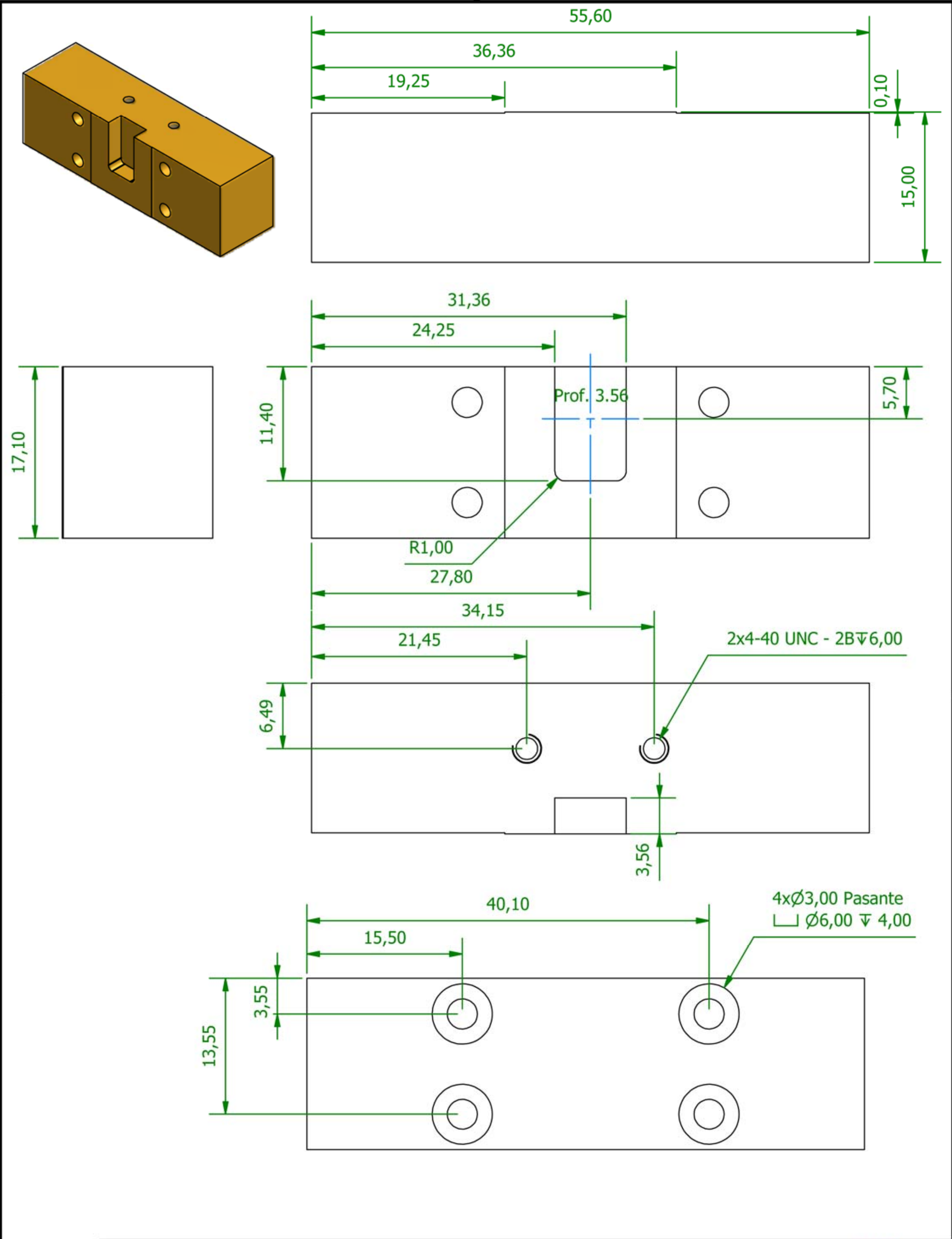


Diseño de	Revisado por	Aprobado por	Fecha	Fecha	Unid: mm
Juan Luís Cano				23/02/2009	
Centro Astronómico de Yebes - CAY		Material: Latón; Acabado: Oro Blando (4um)			
		YKa2533_1 - Tapa		Edición	Hoja 1 / 1



Designed by	Checked by	Approved by	Date	Date
Juan Luís Cano				02/04/2009

Centro Astronómico de Yebes - CAY	Modificaciones para LEDs		
	YKa2533_1 - Tapa_LEDs	Edition	Sheet 1 / 1



Diseño de	Revisado por	Aprobado por	Fecha		Fecha	Unid: mm
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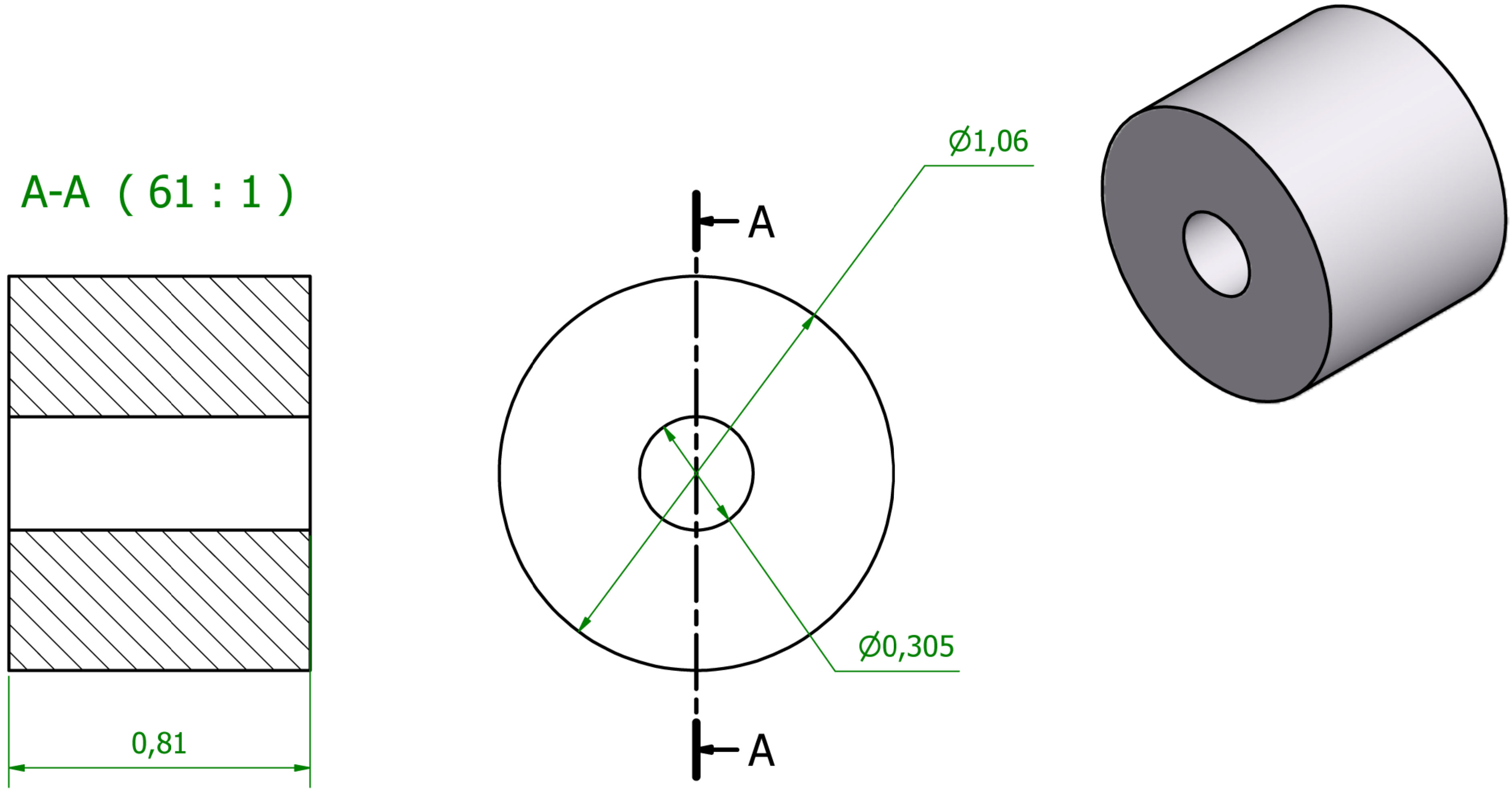
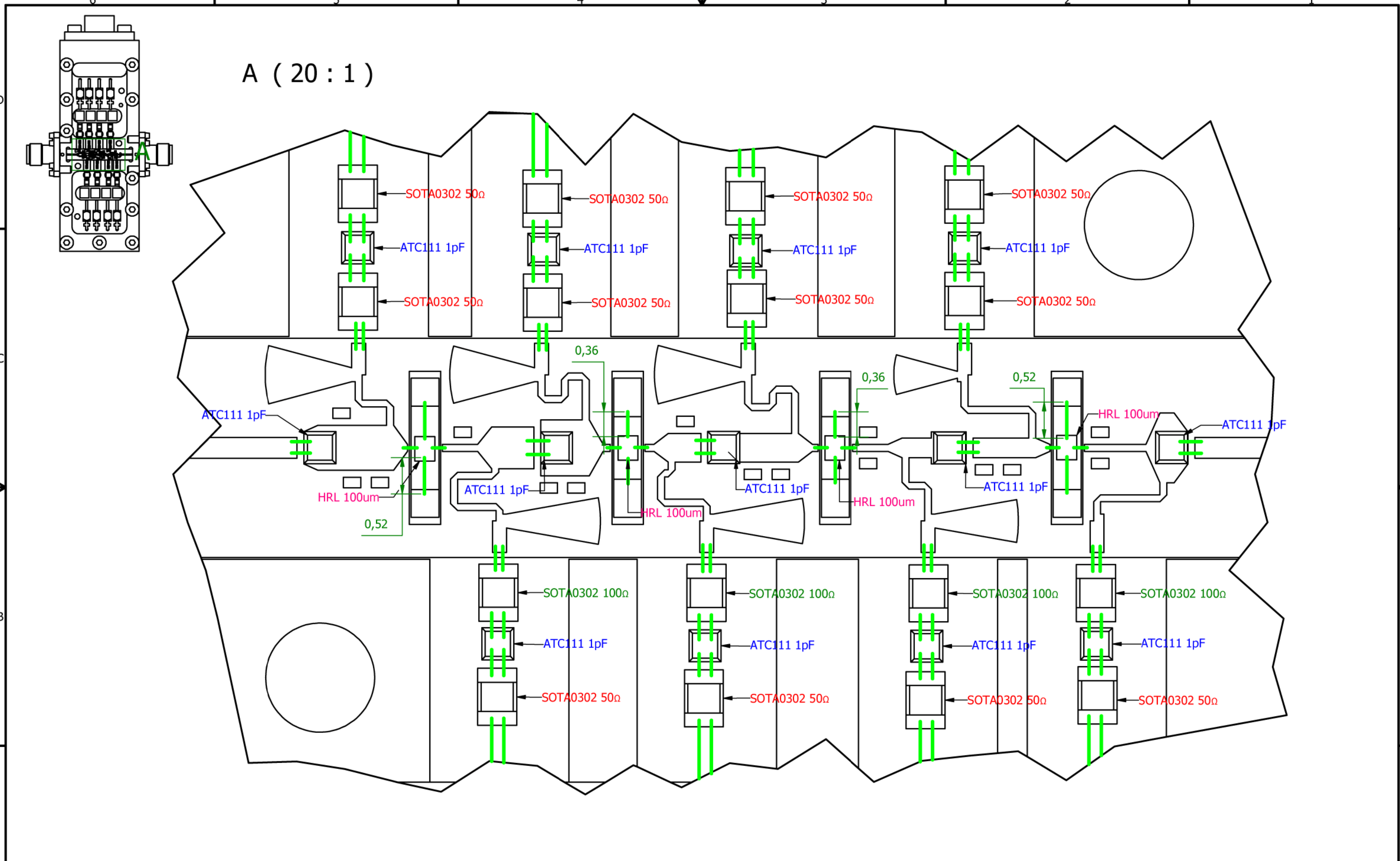
Centro Astronómico de Yebes - CAY		Material: Latón; Acabado: Oro Blando (4um)				
		YKa2533_1 - Acceso Guía			Edición	Hoja 1 / 1

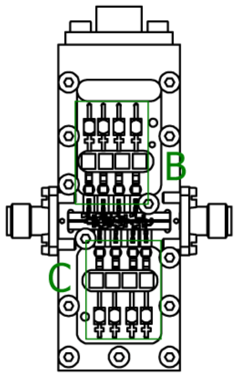


Diseño de	Revisado por	Aprobado por	Fecha		Fecha	Unid: mm
Juan Luís Cano					23/02/2009	
Centro Astronómico de Yebes - CAY	Material: Latón; Acabado: Oro Blando (4um)					
	YKa2533_1 - Adaptador				Edición	Hoja 1 / 1

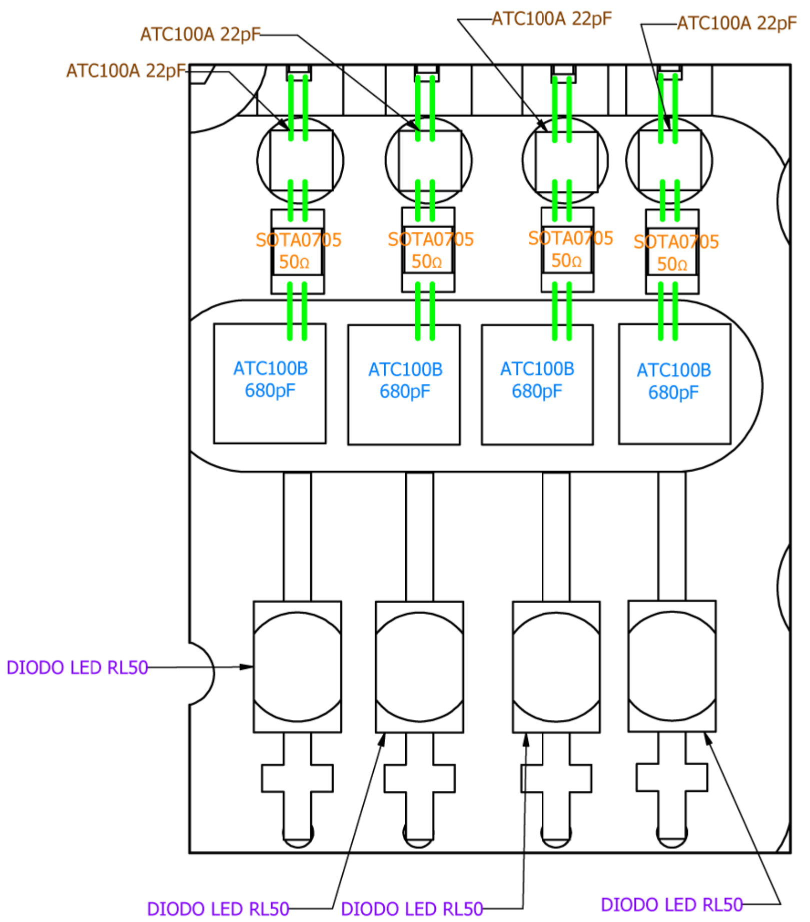


Diseño de	Revisado por	Aprobado por	Fecha	Fecha	Unid: mm
Juan Luís Cano				23/02/2009	

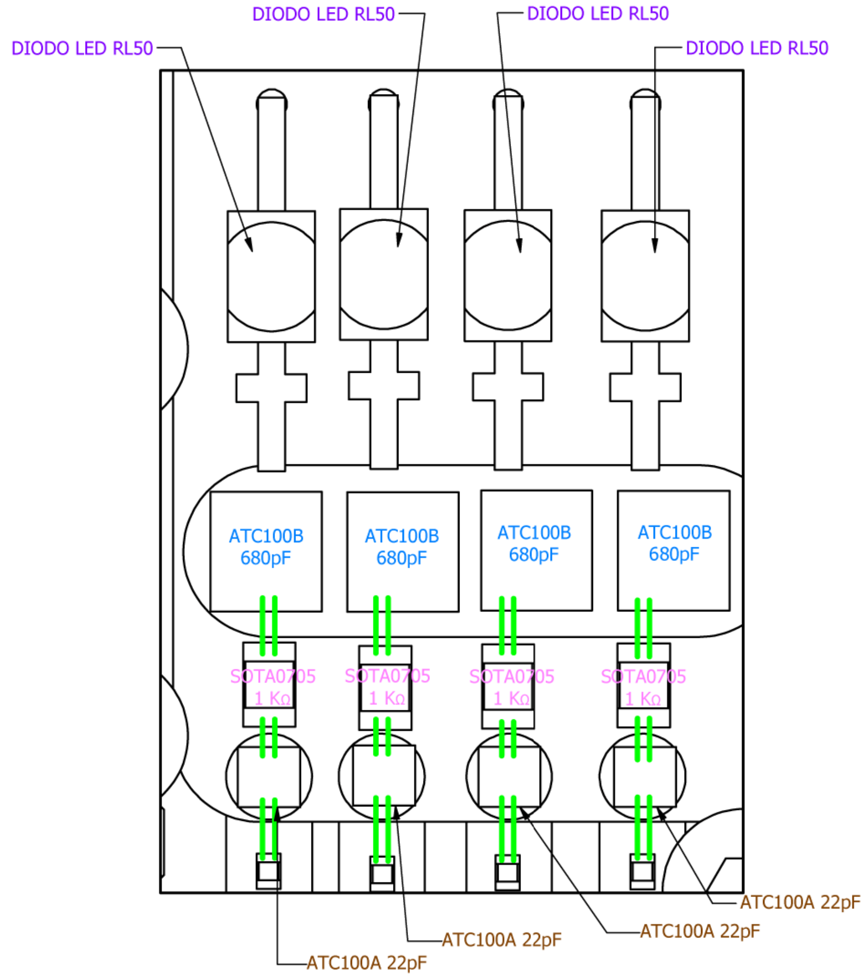
Centro Astronómico de Yebes - CAY	Componentes		
	YKa2533_1 - Componentes	Edición	Hoja 1 / 2



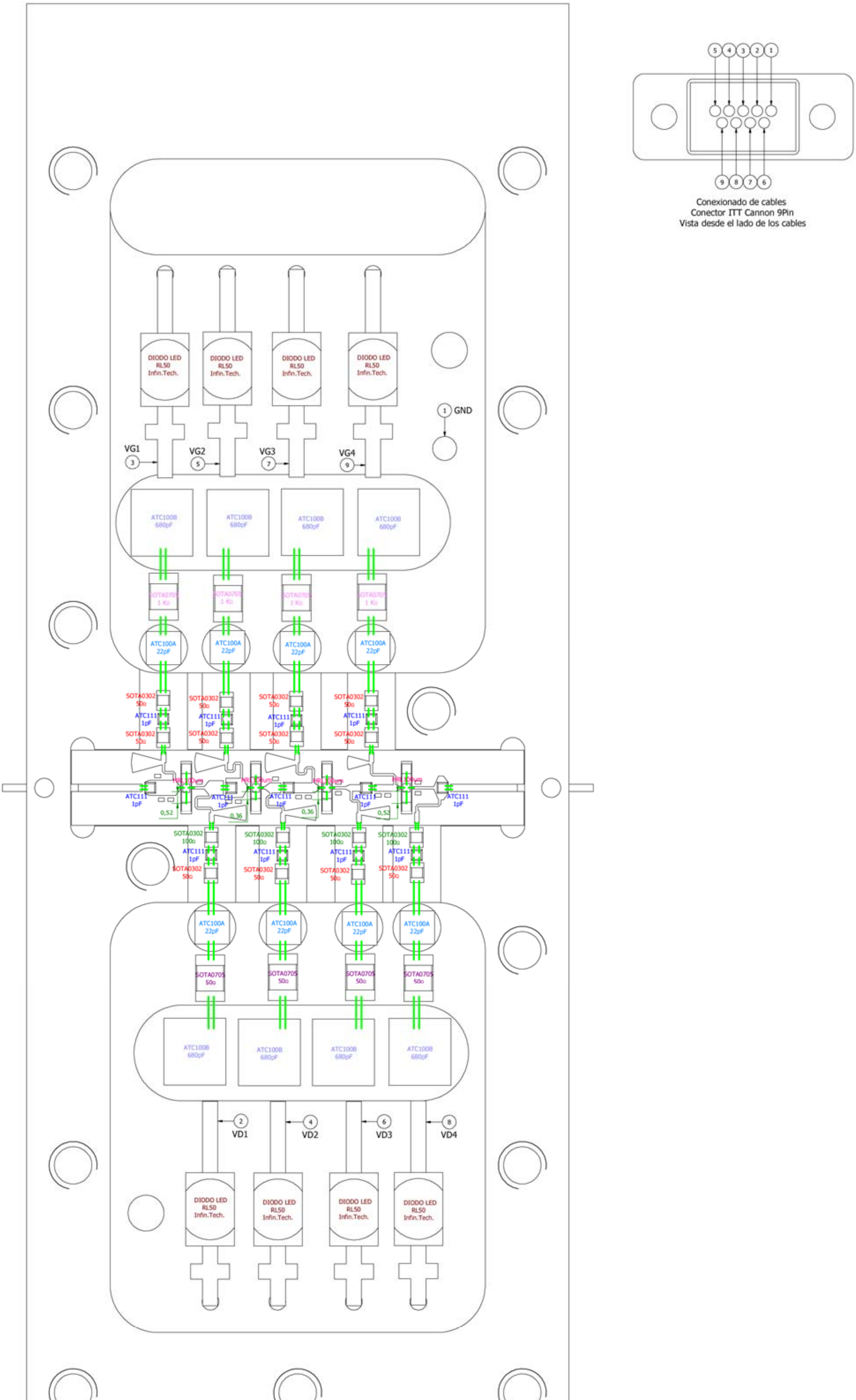
C (8 : 1)



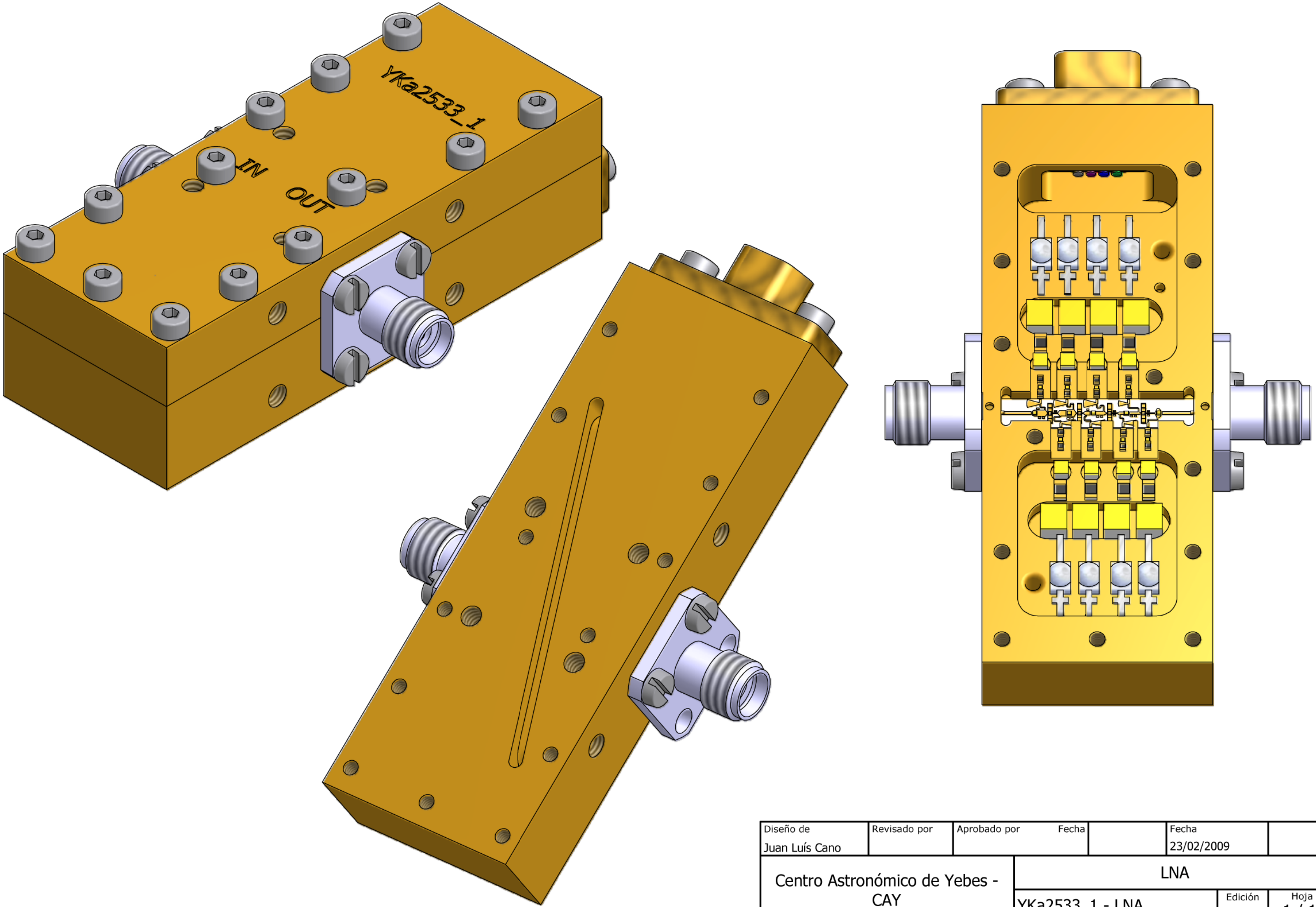
B (8 : 1)



Diseño de	Revisado por	Aprobado por	Fecha	Fecha	Unid: mm
Juan Luís Cano				23/02/2009	
Centro Astronómico de Yebes - CAY		Componentes			
		YKa2533_1 - Componentes		Edición	Hoja 2 / 2



Designed by	Checked by	Approved by	Date		Date	Unid: mm
Juan Luís Cano					25/02/2009	
Centro Astronómico de Yebes - CAY			Colocación de los dispositivos			
			YKa2533_1 - Dispositivos		Edition	Sheet 1 / 1

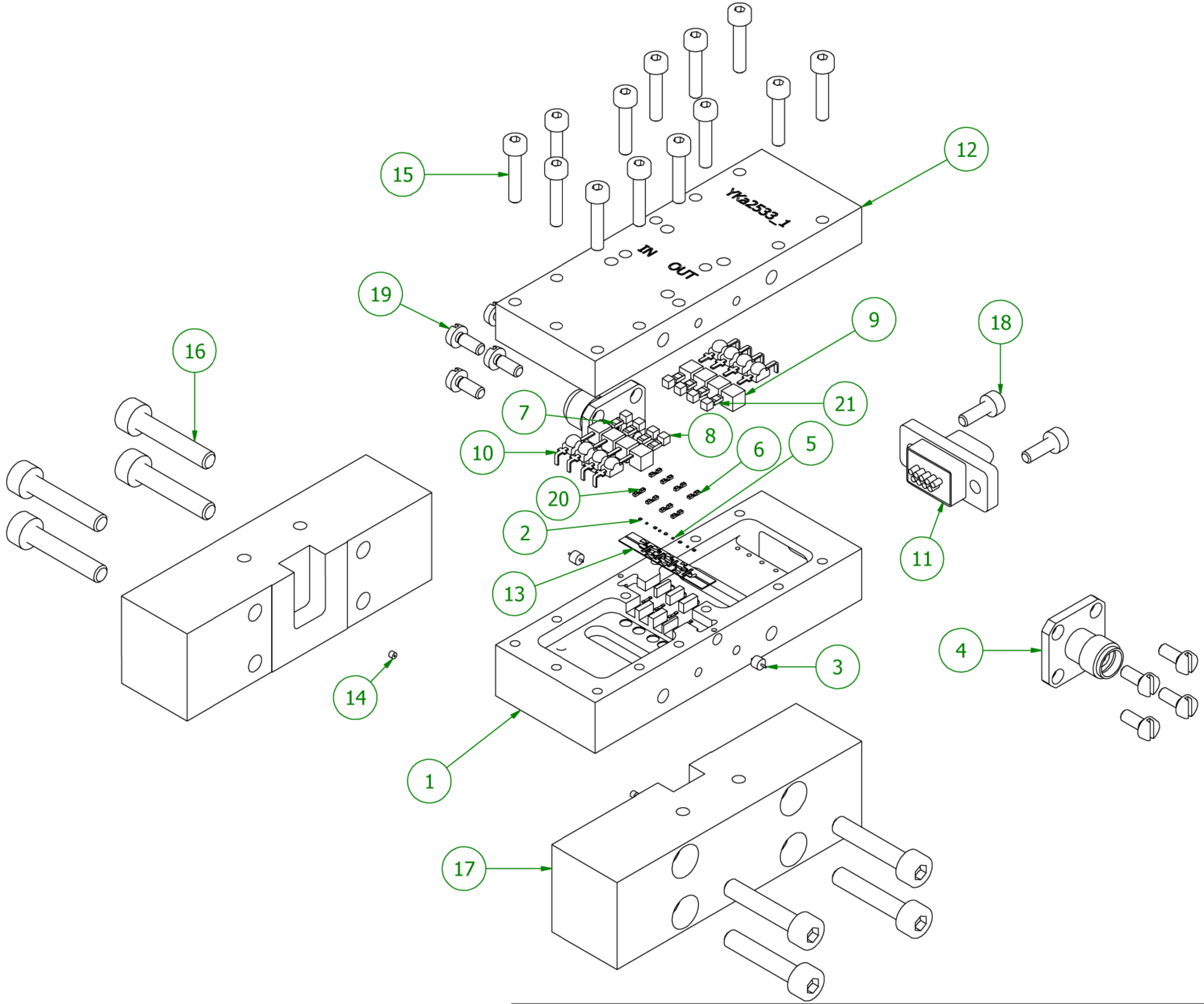


Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luís Cano				23/02/2009

Centro Astronómico de Yebes - CAY	LNA		
	YKa2533_1 - LNA	Edición	Hoja 1 / 1

Lista de piezas

ELEME	CT	Nº DE PIEZA	DESCRIPCI
1	1	Caja	Ver Plano
2	13	Condensador_1pF	ATC111
3	2	Glass_Bead	
4	2	23_SK-50-0-51 Huber+Suhner	Conector K - 4H
5	4	Transistor	HRL 100um
6	12	Resistencia_SOTA S0302AF	50 Ohm
20	4	Resistencia_SOTA S0302AF	100 Ohm
7	4	Resistencia_SOTA S0705AF	50 Ohm
8	8	Condensador ATC100A_CA	22 pF
9	8	Condensador ATC100B_CA	680 pF
10	4	Diodo_LED_RL50 InfineonTech	
11	1	DC_Connector ITTCannon_9	
12	1	Tapa	Ver Plano
13	1	PCB_4st	
14	2	Adaptador	Ver Plano
15	13	BS 4168 - M2 x 10	
16	8	BS 4168 - M3 x 16	
17	2	Acceso_Guia	Ver Plano
18	2	BS 4168 - M2 x 6	
19	8	BS 4183 - M2 x 5	
21	4	Resistencia_SOTA S0705AF	1 KOhm



Diseño de: Juan Luís Cano
Revisado por
Aprobado por
Fecha
Fecha: 23/02/2009

Centro Astronómico de Yebes - CAY

Lista de Piezas

YKa2533_1 - Montaje

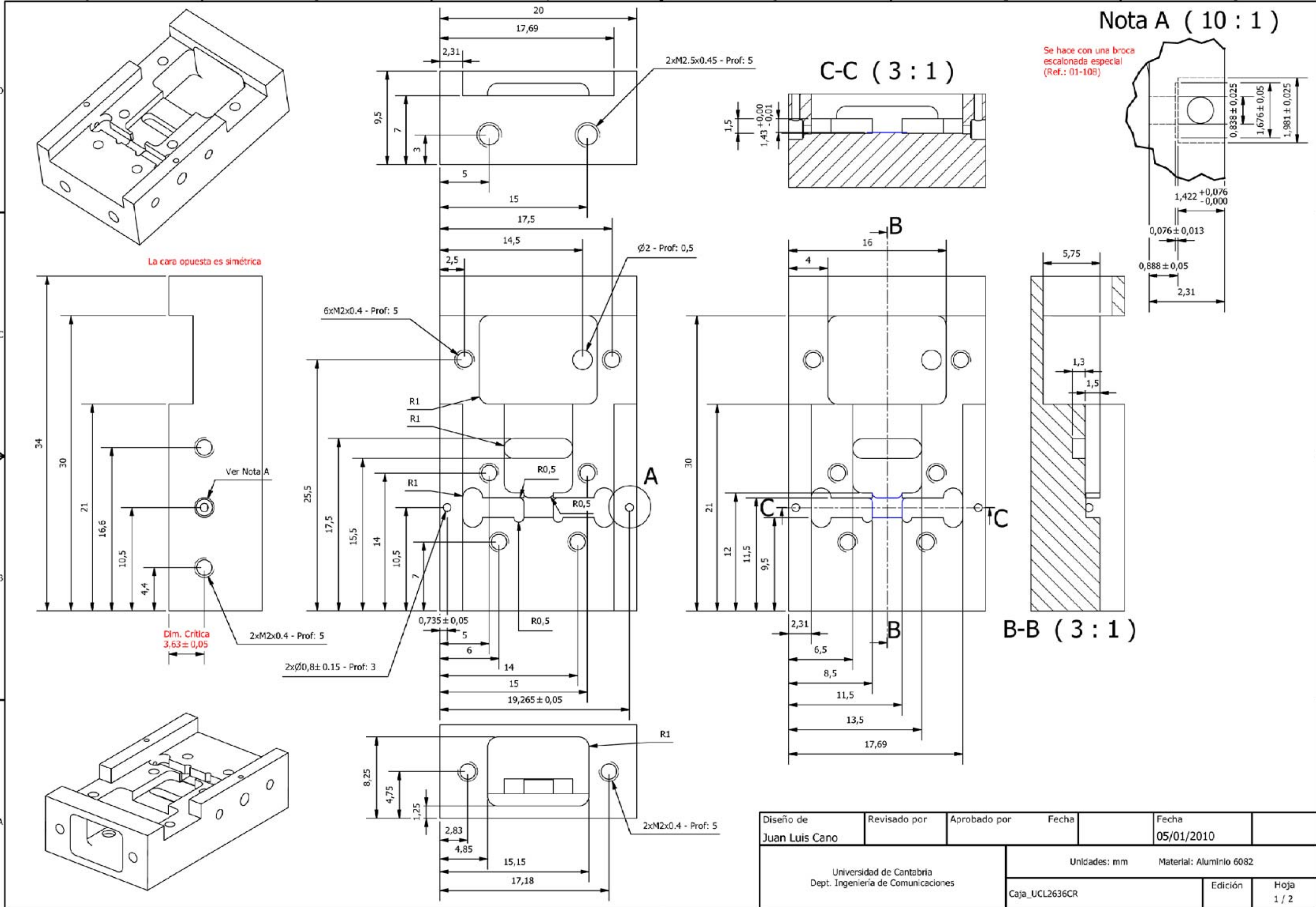
Edición

Hoja 1 / 1

Annex IV

MMIC LNA Module Drawings

No.	Drawing Name	Description
1	Caja_UCL2636CR 1/2	Module dimensions
2	Caja_UCL2636CR 2/2	Cover dimensions
3	Assembly	Components assembly
4	LNA	Artist view of the assembly
5	Despiece	Part list and assembly procedure

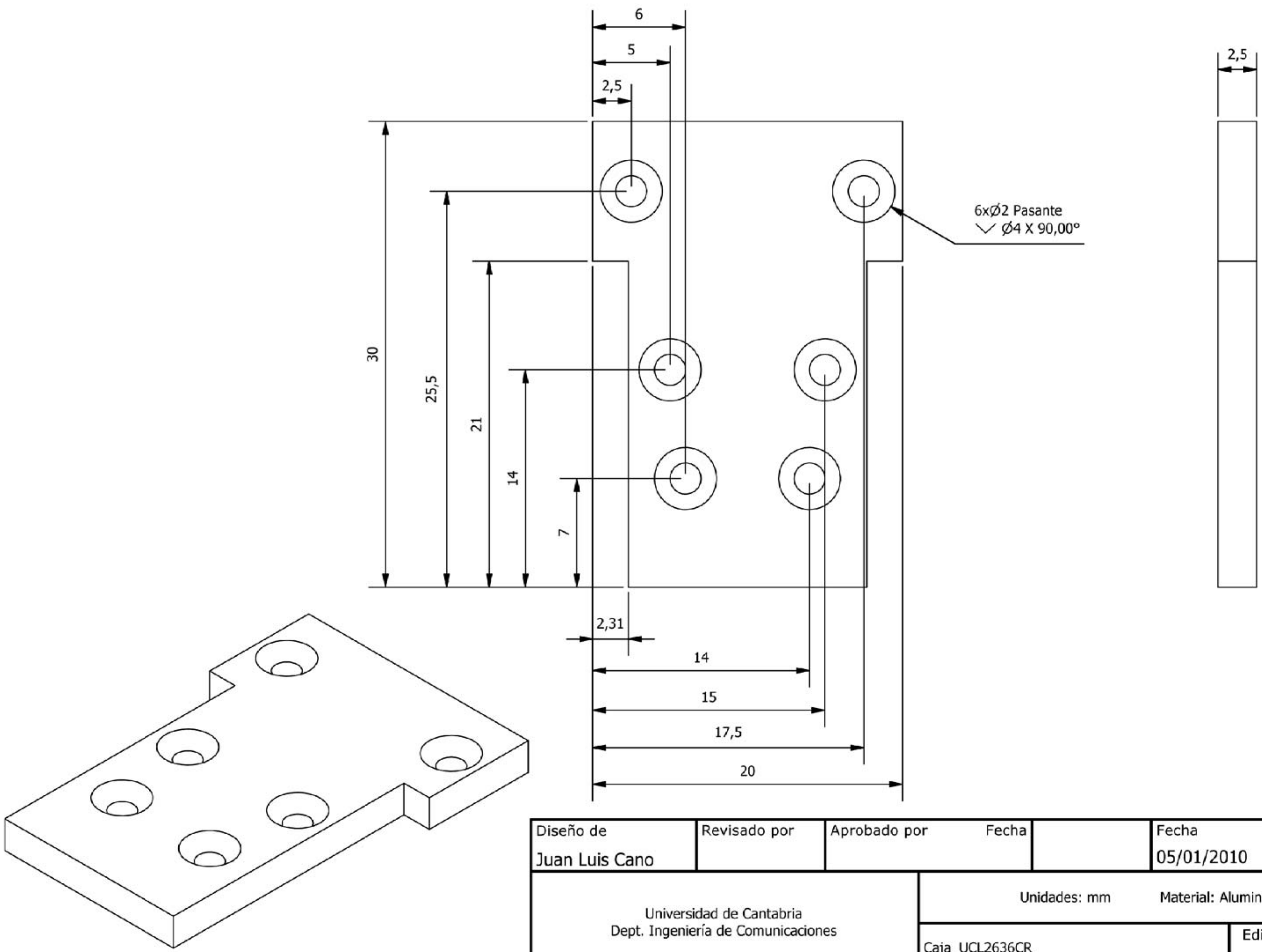


Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				05/01/2010

Universidad de Cantabria
Dept. Ingeniería de Comunicaciones

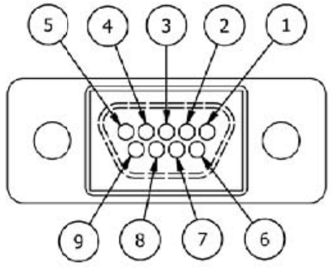
Unidades: mm | Material: Aluminio 6082

Caja_UCL2636CR | Edición | Hoja 1 / 2

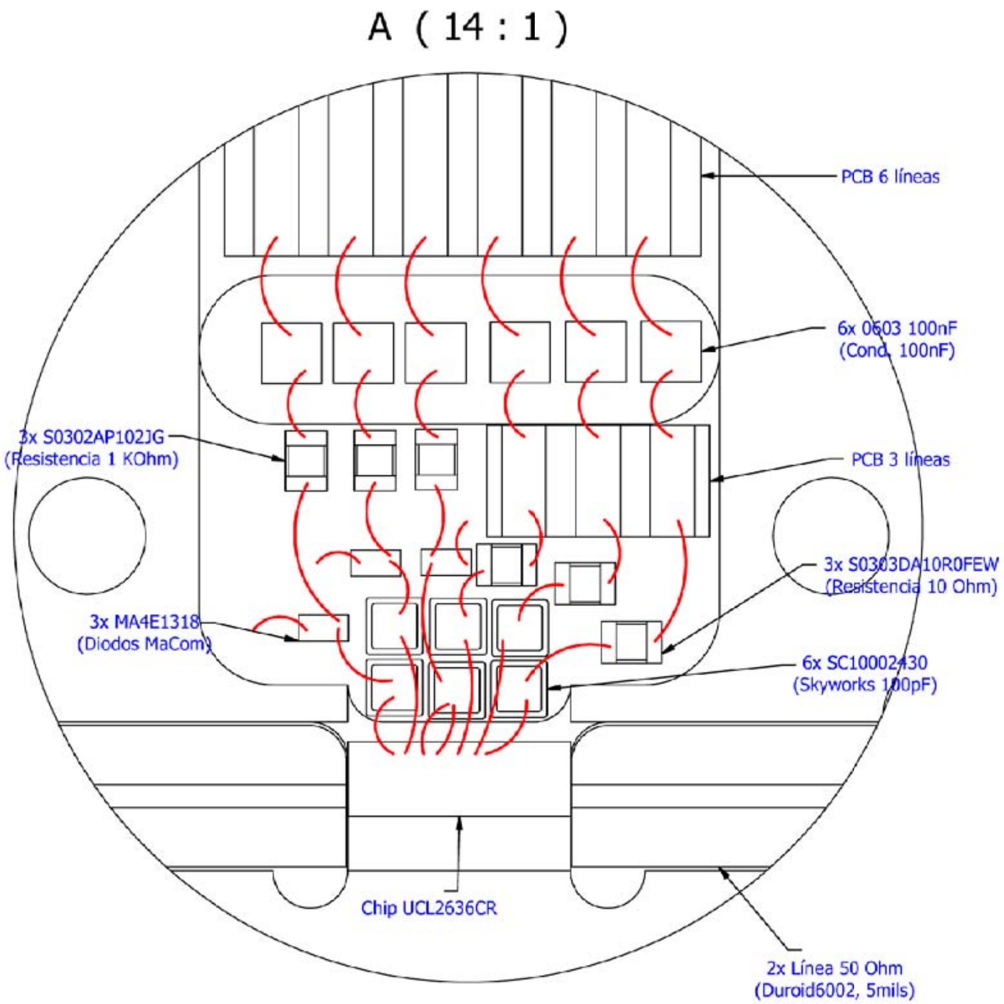


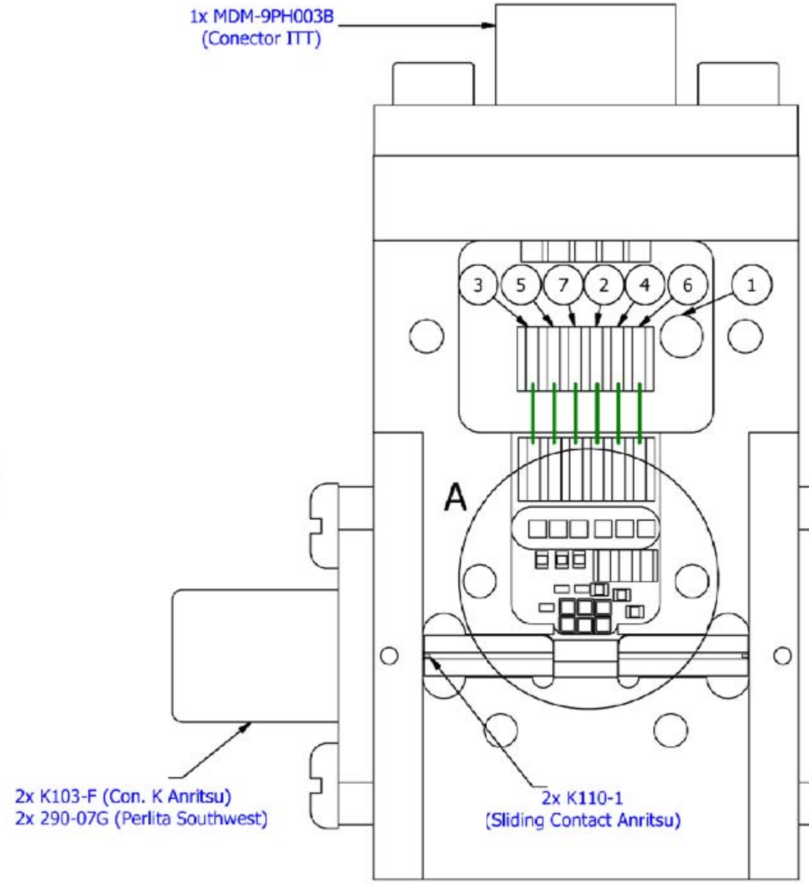
Diseño de	Revisado por	Aprobado por	Fecha		Fecha	
Juan Luis Cano					05/01/2010	
Universidad de Cantabria Dept. Ingeniería de Comunicaciones			**Unidades:** mm		**Material:** Aluminio 6082	
			Caja_UCL2636CR		Edición	Hoja 2 / 2

Leyenda:
Azul: Componentes
Rojo: Bonding wire (preferible Ø17um)
Verde: Cable LakeShore WQL-32



Pinout	
Cable	Señal
1	GND
2	Vd1
3	Vg1
4	Vd2
5	Vg2
6	Vd34
7	Vg34
8	NC
9	NC





Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				15/02/2010

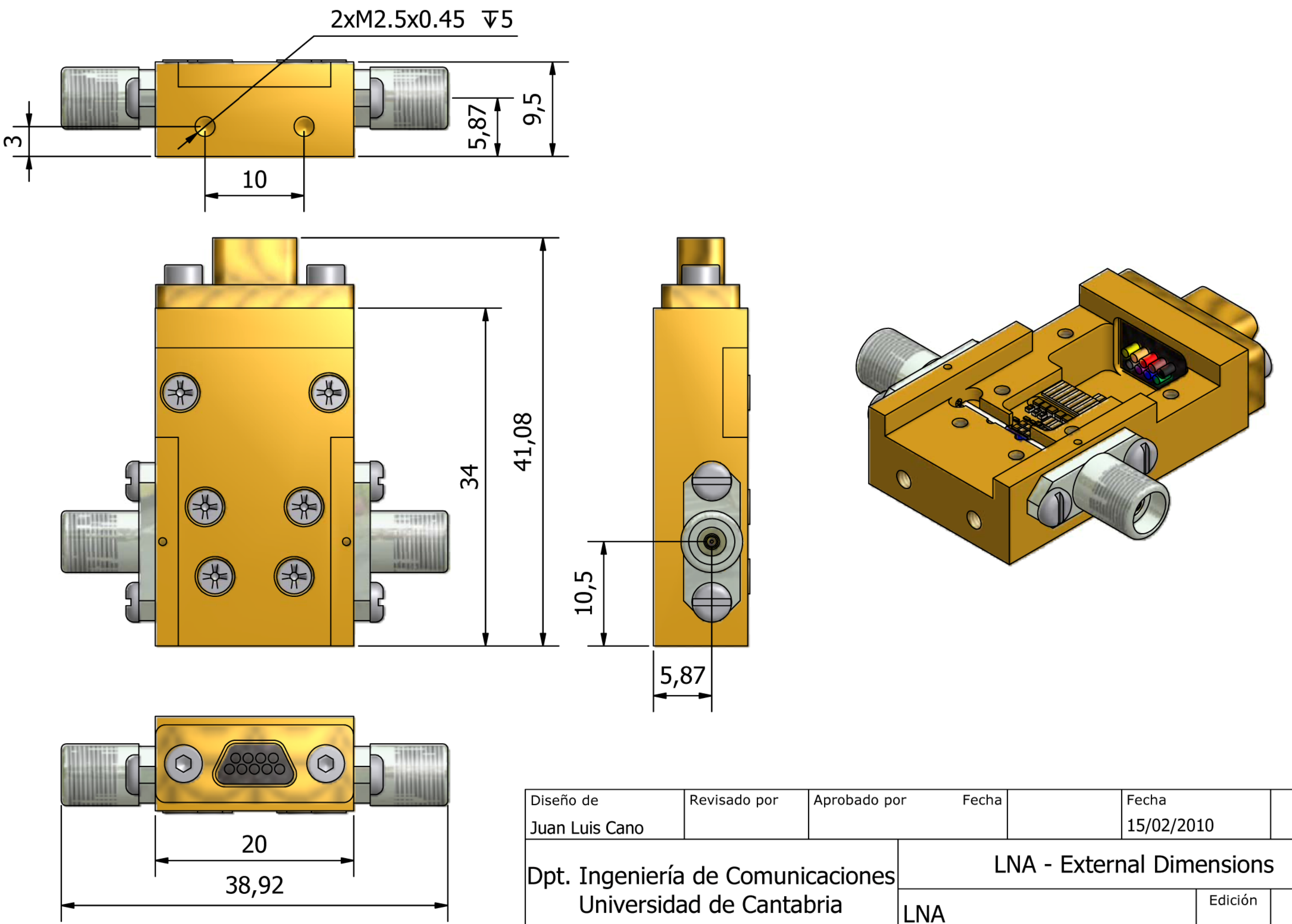
Dpt. Ingeniería de Comunicaciones
Universidad de Cantabria

Assembly - Components

Assembly

Edición

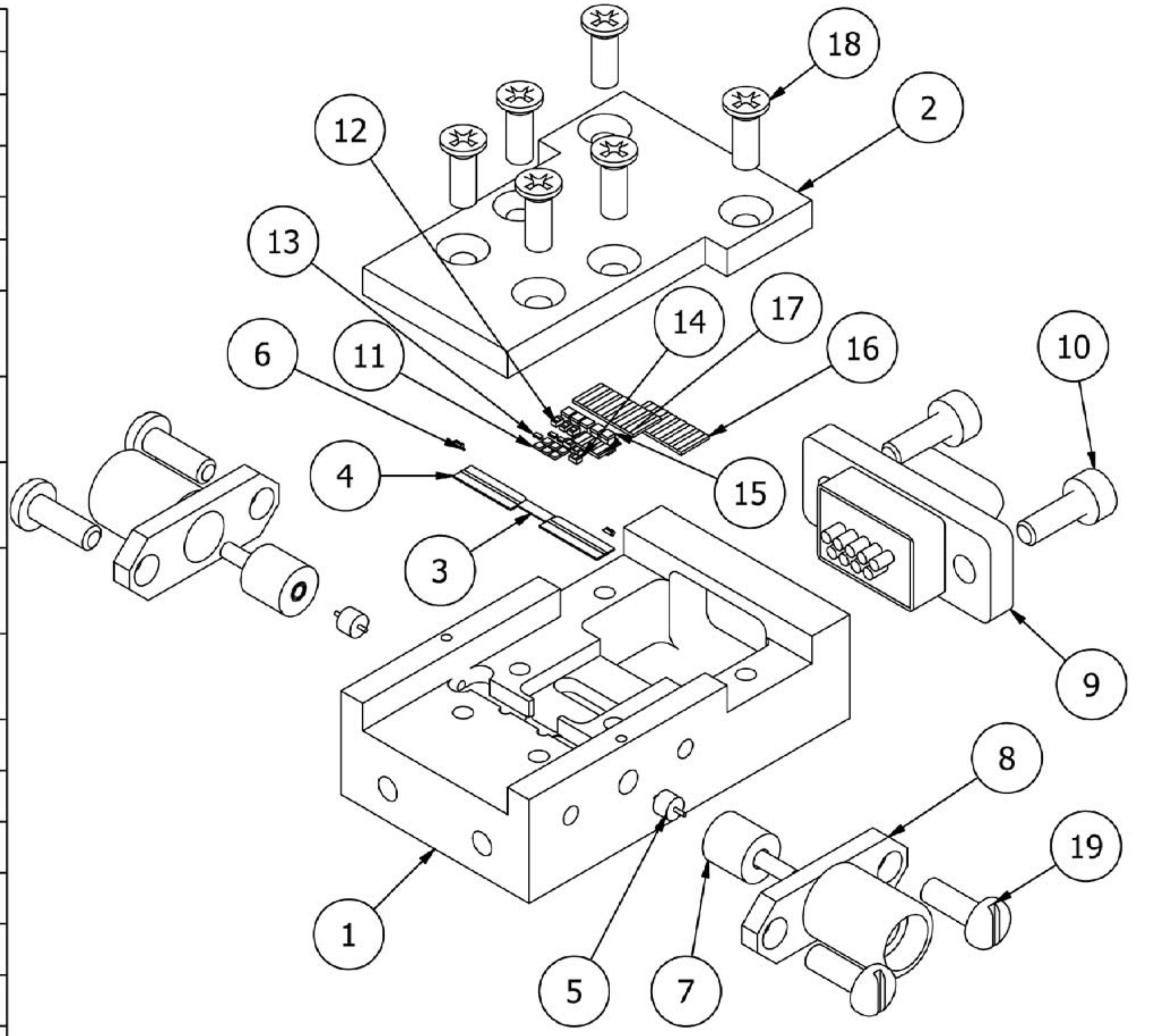
Hoja 1 / 1



Diseño de Juan Luis Cano	Revisado por	Aprobado por	Fecha	Fecha 15/02/2010	
Dpt. Ingeniería de Comunicaciones Universidad de Cantabria		LNA - External Dimensions			
		LNA		Edición	Hoja 1 / 1

Lista de piezas

ELEME	CTD	Nº DE PIEZA	DESCRIPCIÓN
1	1	Module	
2	1	CoverRF	
3	1	Chip UCL2636CR	
4	2	Duroid_50ohm	
5	2	Glass_Bead 290-07G	
6	2	sliding contact K110-1	
7	2	K-connector insert	
8	2	K-connector K103-F	
9	1	ITTCannon MDM-9PH003B	
10	2	M2x0,4 x 6	
11	6	SC10002430	100 pF
12	3	S0302AP	1 KOhm
13	3	MA4E1318	
14	3	S0303	10 Ohm
15	6	C0603	100 nF
16	2	PCB 6 líneas	
17	1	PCB 3 líneas	
18	6	M2x0,4 x 6	
19	4	M2x0,4 x 6	



Diseño de	Revisado por	Aprobado por	Fecha	Fecha
Juan Luis Cano				15/02/2010

Dpt. Ingeniería de Comunicaciones
Universidad de Cantabria

Lista de Piezas

Despiece | Edición | Hoja 1 / 1

Publications

Articles

1. J. L. Cano, N. Wadefalk, and J. D. Gallego-Puyol, “Ultra-Wideband Chip Attenuator for Precise Noise Measurements at Cryogenic Temperatures”, submitted to *IEEE Trans. Microwave Theory and Techniques*. March 2010.
2. A. Tribak, J. L. Cano, A. Mediavilla, and M. Boussouis, “Octave Bandwidth Compact Turnstile-Based Orthomode Transducer”, submitted to *IEEE Microwave and Wireless Components Letters*. March 2010.
3. J. L. Cano, A. Tribak, R. Hoyland, A. Mediavilla, and E. Artal, “Full Band Waveguide Turnstile Junction Orthomode Transducer with Phase Matched Outputs”, accepted for publication in *Int. J. RF and Microwave CAE*. 2010. DOI: 10.1002/mmce.20437
4. J. L. Cano and E. Artal, “Cryogenic Technology Applied to Microwave Engineering”, *Microwave Journal*, vol. 52, no. 12, Dec. 2009. pp. 70-80.
5. M. Chaibi, T. Fernández, J. Rodriguez-Tellez, J. L. Cano, and M. Aghoutane, “Accurate Large-Signal Single Current Source Thermal Model for GaAs MESFET/HEMT”, *Electronics Letters*, vol. 43, no. 14, July 2007, pp. 775-777.

International Conference Papers

1. E. Artal, M. L. de la Fuente, B. Aja, J. L. Cano, E. Villa, R. Hoyland, J. A. Rubiño-Martín, R. Génova, “Cosmic Microwave Background Polarization Receivers: QUIJOTE Experiment”, submitted to the *40th European Microwave Conference*, Paris, France.
2. A. Tribak, A. Mediavilla, J. L. Cano, M. Boussouis, and K. Cepero, “Ultra-Broadband Low Axial Ratio Corrugated Quad-Ridge Polarizer”, *Proc. 39th European Microwave Conference*, Rome, Italy, 29 Sept. – 1 Oct. 2009, pp. 73-76.

3. J. L. Cano and J. D. Gallego-Puyol, “Estimation of Uncertainty in Noise Measurements Using Monte Carlo Analysis”, *RadioNET-FP7 1st Engineering Forum Workshop,* Gothemburg, Sweden, 23-24 June, 2009. Available: www.radionet-eu.org/fp7wiki/doku.php?id=na:engineering:ew:1stew

4. J. L. Cano, B. Aja, E. Villa, M. L. de la Fuente, E. Artal, “Broadband Back-End Module for Radio-Astronomy Applications in the Ka-Band”, *Proc. 38th European Microwave Conference*, Amsterdam, The Netherlands, 27 – 31 Oct. 2008, pp. 1113-1116.

5. M. Chaibi, T. Fernández, J. Rodriguez-Tellez, J. L. Cano, A. Mediavilla, and M. Aghoutane, “Accurate Single Current Source Thermal Model for the GaAs MESFET/HEMT Device at Cryogenic Temperatures”, *Proc. 11th International Symposium on Microwave and Optical Technology (ISMOT),* Rome, Italy, 17-21 Dec., 2007, pp. 271-274.

6. B. Aja, E. Artal, M. L. de la Fuente, J. P. Pascual, and J. L. Cano, “Three Port Stability Analysis of Broadband Millimeter Wave MMIC Amplifier”, *Proc. 1st European Microwave Integrated Circuit Conference*, Manchester, UK, 10-13 Sept., 2006, pp. 399-402.

7. J. L. Cano, T. Fernández, and E. Artal, “Device Modelling at Cryogenic Temperatures Using Pulsed Measurements”, *RadioNET-FP6 3rd Engineering Forum Workshop*, Gothemburg, Sweden, 19 June, 2006. Available: http://www.radionet-eu.org/rnwiki/CryogenicLowNoiseComponentsPresentations

National Conference Papers

1. J. L. Cano, E. Villa, D. Ortiz, and E. Artal, “Transición en Guía WR-28 de Acceso al Criostato para la Medida de Sistemas Enfriados”, *Actas del XXIV Simposium Nacional de la Unión Científica Internacional de Radio (URSI 2009),* Santander, 16-18 Sept., 2009. Available: http://w3.iec.csic.es/URSI/

2. D. Ortiz, E. Villa, J. L. Cano, M. L. de la Fuente, and E. Artal, “Medida de Componentes Pasivos en Criogenia”, *Actas del XXIII Simposium Nacional de la Unión Científica Internacional de Radio (URSI 2009),* Santander, 16-18 Sept., 2009. Available: http://w3.iec.csic.es/URSI/

3. J. L. Cano, B. Aja, E. Villa, M. L. de la Fuente, and E. Artal, “Módulo Posterior de un Receptor en Banda Ka para Aplicaciones de Radioastronomía”, *Actas del XXIII Simposium Nacional de la Unión Científica Internacional de Radio (URSI 2008),* Madrid, 22-24 Sept., 2008. Available: http://w3.iec.csic.es/URSI/

4. J. A. Rubiño-Martín *et al.*, “The QUIJOTE CMB Experiment”, *Proc. VIII Scientific Meeting of the Spanish Astronomical Society*, Santander, Spain, 7-11 July, 2008. arXiv:0810.3141v1

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